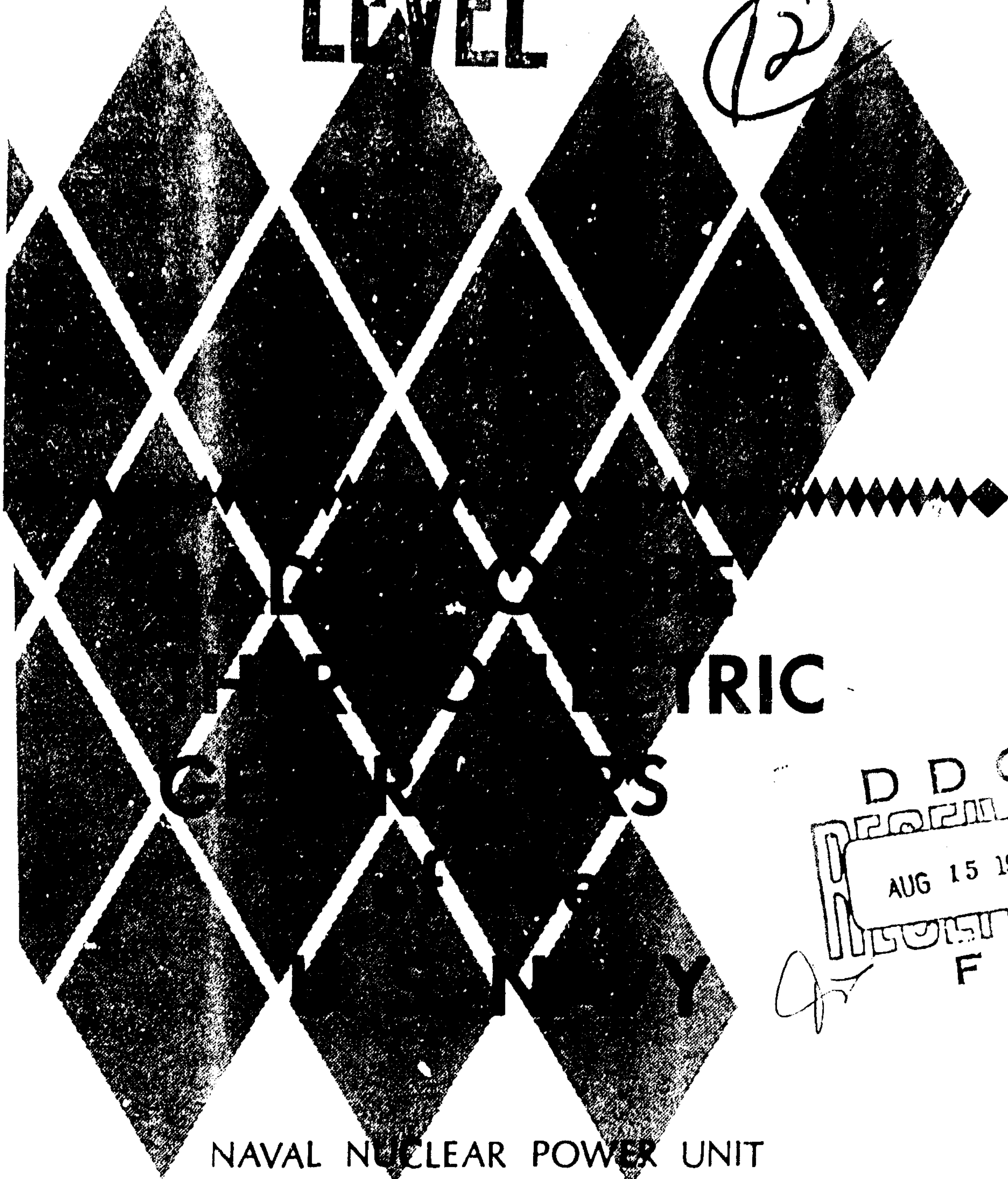



NAVAL NUCLEAR POWER UNIT
PORT HUENEME, CALIFORNIA

VOLUME 10, 1 JULY 1978

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| RTG | Thermoelectricity |
| Sentinel | URIPS |

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This document disseminates information on the development and application of radioisotope thermoelectric generators (RTGs) within the Navy. A chapter is included which describes what an RTG is, how it operates, and generally when it can be used. Other chapters examine potential applications in more depth, summarize current RTG missions, and describe the Navy's latest development effort, the half-watt RTG. A chapter is also devoted to providing technical information such as electrical power output and current/voltage characteristics for each model of RTG in the Navy's inventory.

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For those engineers and scientists in search of a long life, reliable power source instructions on how to obtain an RTG and a listing of services available from the Naval Nuclear Power Unit are provided. A table is presented which lists RTGs in the Navy's inventory that are not presently assigned to missions and are available for loan.

## PREFACE

This document disseminates information on the development and application of radioisotope thermoelectric generators (RTGs) within the Navy. A chapter is included which describes what an RTG is, how it operates, and generally when it can be used. Other chapters examine potential applications in more depth, summarize current RTG missions, and describe the Navy's latest development effort, the half-watt RTG. A chapter is also devoted to providing technical information such as electrical power output and current/voltage characteristics for each model of RTG in the Navy's inventory.

For those engineers and scientists in search of a long life, reliable power source, instructions on how to obtain an RTG and a listing of services available from the Naval Nuclear Power Unit are provided. A table is presented which lists RTGs in the Navy's inventory that are not presently assigned to missions and are available for loan.

Suggestions for improving the effectiveness of this publication and the Navy's RTG Program will be welcomed, as will requests for more information or additional copies of this document. All correspondence and inquiries should be addressed to the Officer-in-Charge, Code 70, Naval Nuclear Power Unit, Port Hueneme, CA 93043, commercial (805) 982-5323 or AUTOVON 360-5323. A pre-addressed post card is attached to the rear cover for your added convenience.

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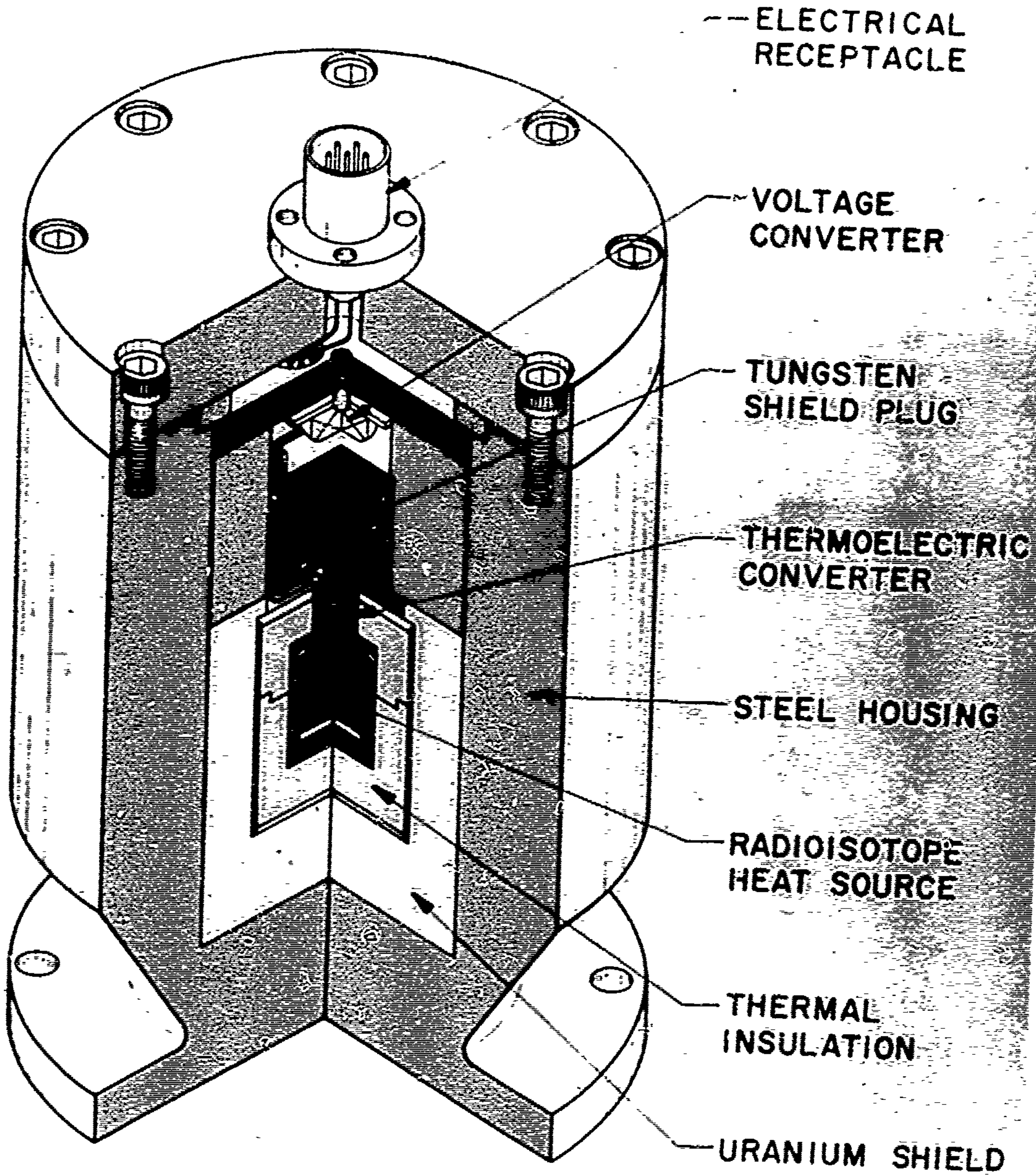



Figure 1-1. Millibatt-1000 Deep Ocean Radioisotope Thermoelectric Generator

# CHAPTER ONE

# RADIOISOTOPE THERMOELECTRIC GENERATORS

**1.1 RADIOISOTOPE THERMOELECTRIC GENERATORS.** Nuclear energy usually calls to mind large concrete-domed reactors capable of generating hundreds of megawatts of electrical power for the utility industry. In just the last 20 years, however, the atom has been put to a much more modest use in a type of electrical power source known as a radioisotope thermoelectric generator (RTG). These devices typically generate a relatively small amount of power — from fractions of a watt to several hundred watts. In this power range, these devices have an interesting and unique advantage over other power sources: they can be designed to operate continuously for periods of time in excess of 10 years without surveillance or an external energy source. Thus there is no need for such things as fossil fuels, umbilicals, power lines, or even routine maintenance.

A radioisotope thermoelectric generator consists basically of five components: an encapsulated radioisotope heat source, thermal insulation, a thermoelectric converter, a voltage converter, and a biological radiation shield. The physical arrangement of these components is illustrated in Figure 1-1, a cross section of a typical deep-ocean RTG.

Thermal energy generated within the heat source by decay particles colliding with the isotope material is transformed into low-voltage DC electrical power by the thermoelectric converter. Figure 1-2, a schematic diagram of RTG components, shows the detailed interconnection of n and p-type semiconductor thermoelements within the thermoelectric converter. Thermal losses are reduced by employing insulation to channel the heat flow through the thermoelements. Radiation originating in the heat source from the radioactive decay process usually requires the provision of a biological shield for personnel protection. The low voltage produced by the thermoelectric converter is normally transformed to a higher potential by power conditioning equipment in order to match the power requirement of the electrical load.

**1.2 RADIOISOTOPE FUELS.** The principal radioisotope fuels used in RTGs are Strontium-90 and Plutonium-238. Differences in their radiation, half-lives, and cost result in significant differences in their application. Plutonium-238 has been used extensively in space applications because of its relatively longer half-life (86.4 years versus 27.7 years), its minimum shielding requirements, and consequent light generator weight. Because of its long half-life and radiation characteristics, Plutonium-238 is also used in biomedical applications such as the miniature nuclear batteries in heart pacemakers. Strontium-90, because it can be obtained more economically, is used in terrestrial applications even though heavy shielding is required due to bremsstrahlung production.

**1.3 RTG APPLICATIONS.** Many advantages can accrue through the use of RTGs in lieu of conventional power generating devices when special requirements arise. RTGs provide reliable, long term unattended operation ideal for remote or inaccessible areas such as outer or dark space, the ocean floor, the arctic and antarctic regions, and the interior of the human body. Their use frees the designer from the constraints normally imposed by the limited availability of electrical power lines, the limited life of chemical batteries and other similar energy storage devices and the limited availability of sunlight for photovoltaics. Radioisotope thermoelectric generators have proven to be ideal for many applications. The SNAP (Systems for Nuclear Auxiliary Power) series of RTGs is being used extensively to power navigational and weather satellites, deep space probes such as the two Viking Landers which rest on Mars, and scientific equipment such as the Apollo Lunar Surface Experiment Package which remained on the moon. Terrestrial applications such as remote weather facilities in the antarctic region or isolated microwave repeater stations are also well suited projects for the maintenance-free RTG. Other terrestrial uses include powering navigational buoys, meteorological or oceanographic data collection systems, and undersea surveillance systems.

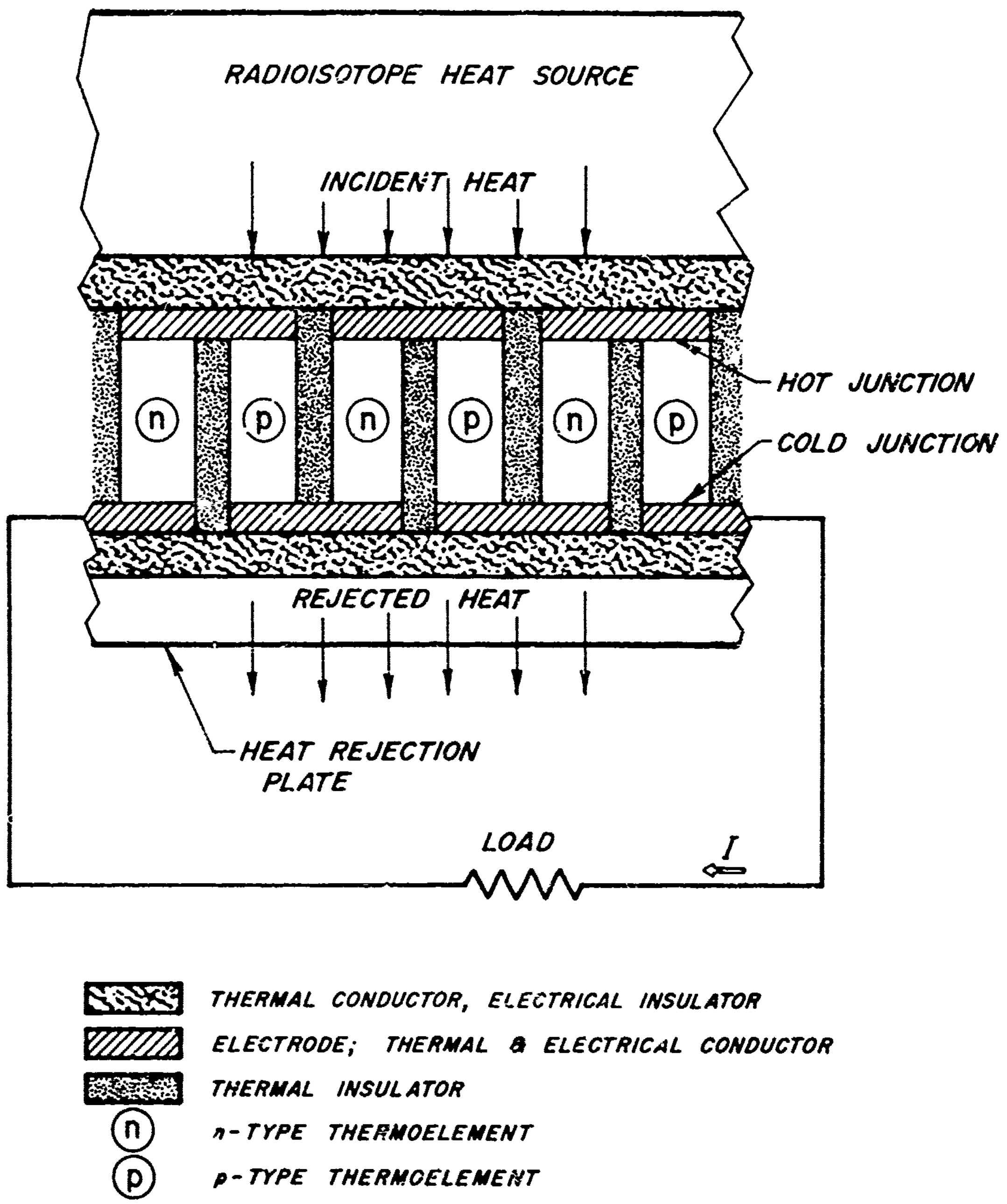



Figure 1-2. Schematic Representation of an RTG with Details of the Thermoelectric Converter.

## CHAPTER TWO

## APPLICATIONS OF RADIOISOTOPE THERMOELECTRIC GENERATORS

### 2.1 GENERAL APPLICATIONS

**2.1.1 RTGs ARE SPECIAL-PURPOSE POWER SOURCES** It must be recognized that RTGs are designed to provide electrical power in situations involving special requirements or unique operating conditions. Some characteristics of RTGs which permit them to meet these special requirements or unique operating conditions include long life, continuous power, no maintenance, silent operation, low life-cycle cost, chemically non-polluting, high energy density (compact size), extreme safety and high adaptability to harsh environments. These characteristics give RTGs many advantages over conventional power generating devices in many situations, some of which are described below.

**2.1.2 RTGs PROVIDE RELIABLE, CONTINUOUS POWER FOR LONG PERIODS.** Navy RTGs are usually designed for lifetimes of at least five years. Ten years of continuous operation is not unusual and Navy RTGs with a 15-year life have been developed. Manufacturers are working toward 20-25 year lifetimes for cardiac pacemaker RTGs. Since the RTGs provide power continuously, the duty cycle of supported electronics need not be severely constrained to conserve power.

**2.1.3 RTGs ARE SELF-CONTAINED, REQUIRE NO REFUELING, AND NO MAINTENANCE.** This makes them ideal for remote areas where manning of systems is undesirable, or inaccessible areas where manning of systems is impractical or impossible, or where replacement of systems is difficult, or dangerous, or costly. Examples of such areas include: outer space; remote terrestrial locations such as islands, mountainous areas, and polar regions; undersea locations; sea surface locations; and inside the human body. Typical uses of RTGs in such remote locations include power for meteorological and oceanographic sensors and data collection systems, communications systems, navigational aids, and undersea surveillance systems.

**2.1.4 RTGs ARE SAFE AND HIGHLY ADAPTABLE TO HARSH ENVIRONMENTS.** Navy RTGs are constructed to meet the design criteria of the International Atomic Energy Agency and the Nuclear Regulatory Commission. This insures the safety of personnel during normal conditions of transport and handling and also under certain hypothetical accident conditions which may occur during shipment or implant. For example, RTGs designed for undersea use include a pressure hull suitable for the depths involved; those for deep ocean use are designed for pressures of 10,000 – 15,000 psi. Whereas conventional batteries lose considerable power at extremely low environmental temperatures, RTGs gain power and operate more efficiently as the ambient temperature decreases. Also, where conventional power sources may be detrimentally affected by exposure to a corrosive atmosphere, there is no effect on the RTG because it is a sealed system.

**2.1.5 RTGs HAVE A RELATIVELY LOW LIFE-CYCLE COST.** At first look, it appears that RTGs are relatively expensive. It is recognized that the initial relative cost may be fairly high; however, since RTGs require no maintenance, their use in long-term missions can reduce considerably the total cost of a mission. When viewed from the standpoint of system life-cycle cost, the use of RTGs in long-term missions is often more cost effective than any other type of power source.

## 2.2 RECENT APPLICATIONS AND CURRENT MISSIONS

### 2.2.1 ARCTIC MISSIONS

**2.2.1.1 RTGs Power Communication Stations in Lake Clark Pass, Alaska.** Five RTG-powered UHF relay stations were installed in October 1977 as part of FAA's Lake Clark Communication Link Project to provide communications for light aircraft flying through Lake Clark Pass; see Figure 2-1. The relay stations are located at altitudes ranging from 2400 to 3650 feet. The power system for each station consists of a Navy RTG and a nickel-cadmium battery pack. At each of four stations a Sentinel-25F RTG provides from 28 to 30 watts of raw power at 2.8 to 3.1 volts; this output is DC-DC converted to recharge the 14-volt battery packs, see Figure 2-2. At the fifth station a SNAP-23A RTG provides 45 to 50 watts of power at 18 volts; this is used through a voltage limiter to recharge a 14-volt battery pack.

The Alaskan Region Office of the Federal Aviation Administration (FAA) deployed these five relay stations to extend the previously established air-to-ground communications network throughout the entire length of this narrow mountain pass. It is now possible for pilots anywhere in the pass to communicate with the flight service station at Kenai Municipal Airport to obtain vital weather information. The successful operation of these five stations has confirmed the suitability and reliability of RTGs for remote, unmanned communications stations; as a result, future FAA plans call for RTG-powered stations to replace the remaining two original repeater stations presently powered by propane-fired thermoelectrics.

**2.2.1.2 RTG Powers Oceanographic Sensors at Fairway Rock, Alaska.** A 25-watt Sentinel-25A RTG (formerly designated LCG-25A) was installed on 11 August 1966 on Fairway Rock, an island in the eastern part of the Bering Strait (Figure 2-3), to provide power for oceanographic sensors which measure water temperature, salinity and velocity; see Figures 2-4 and 2-5. This five-year design life RTG has proven its high reliability by successfully powering the the sensors and related telemetry equipment for more than 11 years.

Since the output power of an RTG decreases gradually as the radioactive fuel decays, it will be necessary to replace this generator in the near future; discussions to plan for its replacement will commence this year.

**Figure 2-1. Lake Clark Pass Looking Southwest from Relay Station Five.**

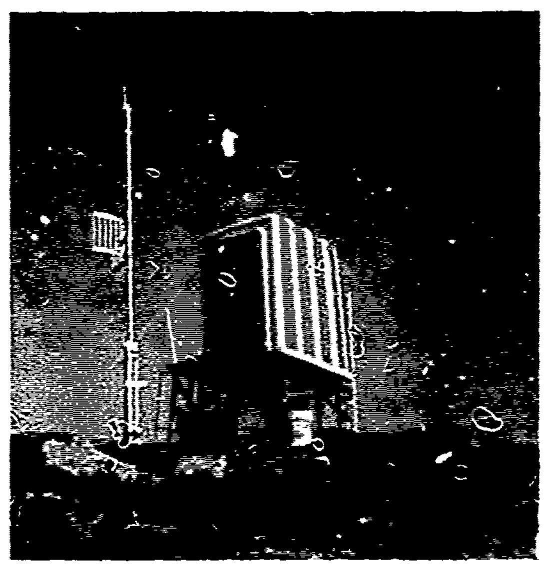


**Figure 2-2. Communications Relay Station Five with Sentinel-25F RTG (Underneath Structure).**

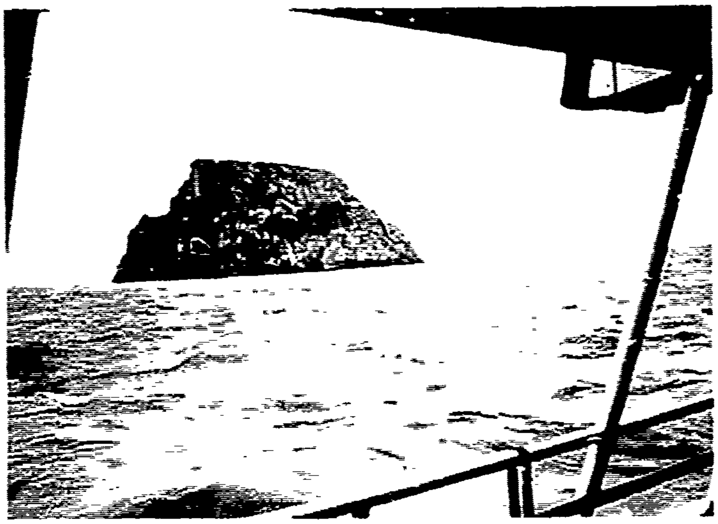


Figure 2-3. Fairway Rock; RTG is Located on the Plateau on top of the Rock.

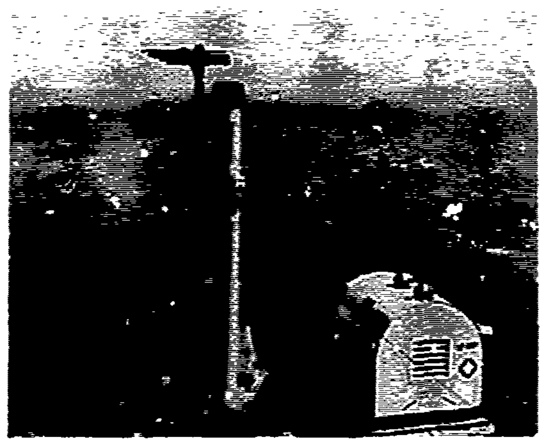


Figure 2-4. Original Installation of the RTG Deployed in its Shipping Container; Antenna on Left is for Telemetry of Data.

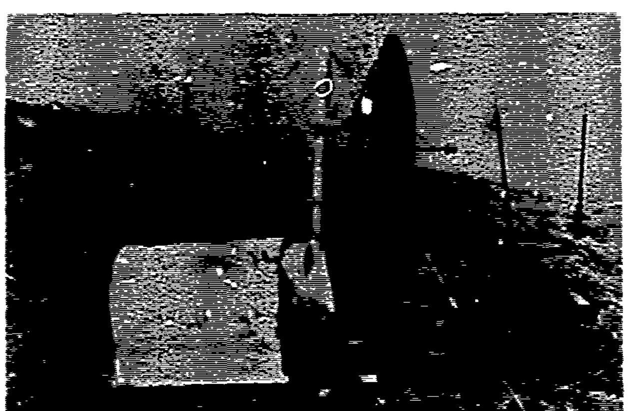


Figure 2-5. The RTG After Several Years of Operation. Original Telemetry Antenna has been Replaced; Old Propane Tanks in Background were part of Power System Replaced by the RTG.

## 2.2.2 ANTARCTIC MISSIONS

**2.2.2.1 RTG Powers Infrasonic Research Station at Windless Bight, Antarctica.** An infrasonic research station consisting of an array of sensors and related telemetry equipment was installed at Windless Bight on the Ross Ice Shelf on 23 November 1976, see Figures 2-6 and 2-7. A Navy 10-watt SNAP-21 RTG not only provides power for the sensors and the telemetry, but also provides waste heat from the RTG to keep the electronics at an acceptable operating temperature; see Figure 2-8.

The National Science Foundation and University of Alaska deployed this research station as part of an effort to understand the complex interaction between the earth's magnetosphere and its ionosphere. The RTG and the station are performing satisfactorily, and approval of the RTG's use on this mission has been extended to January 1980. The reliable operation of this RTG and the success of the project has further shown that an RTG is an ideal power source for remote operations in polar regions.

**Figure 2-6. Erecting Prefabricated Building Around the RTG; Nodwell Vehicle is in Hole Dug to Facilitate Unloading of RTG.**

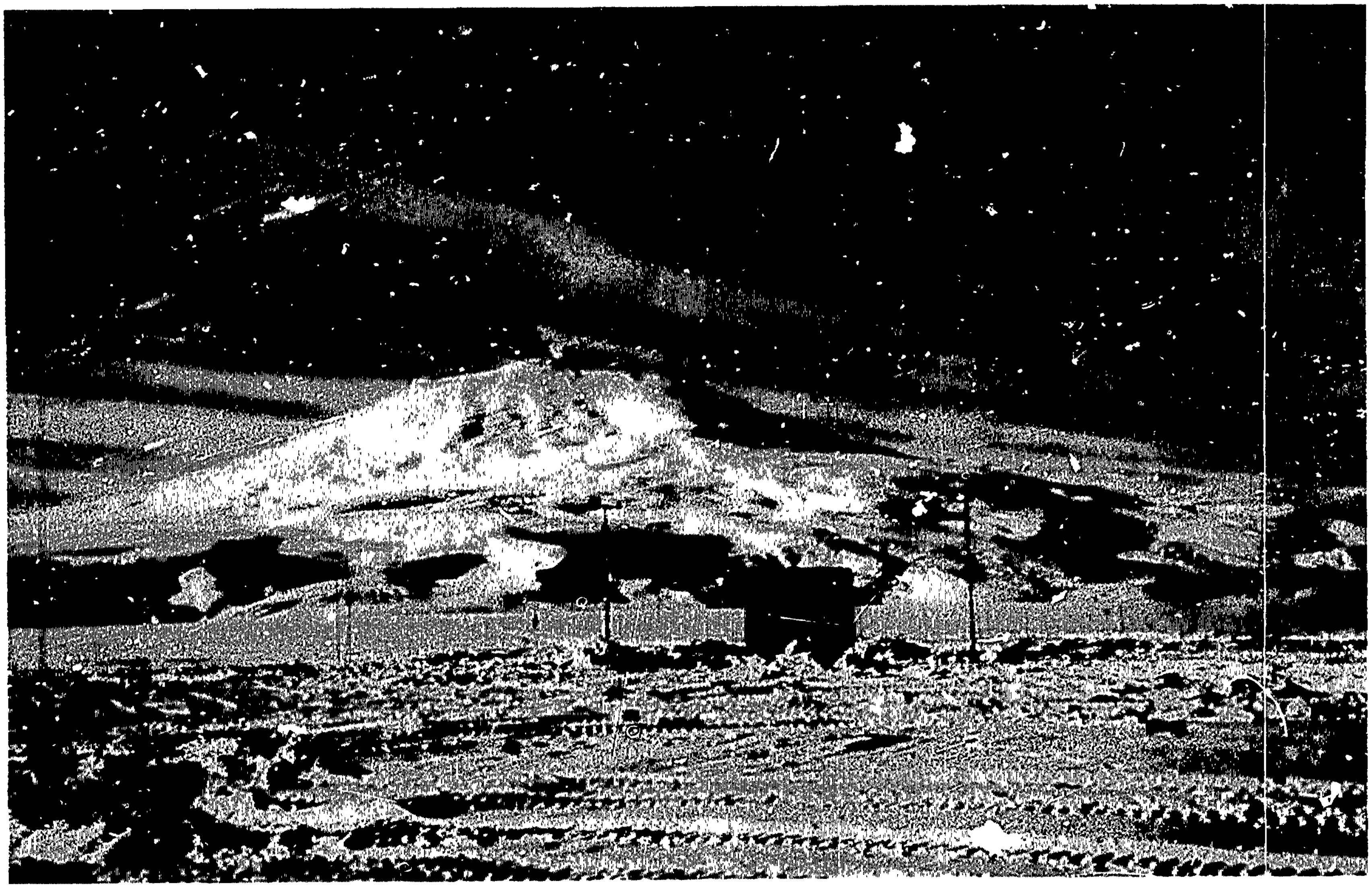


Figure 2-7. Completed University of Alaska Windless Bight Infrasonic Observatory; Active Volcanic Peak in Background is Mount Erebus.

Figure 2-8. Dr. C.R. Wilson of the University of Alaska with RTG and Electronics at Windless Bight, Antarctica.

**2.2.2.2 RTG Powers Automatic Weather Station at Marble Point, Antarctica.** The National Science Foundation (NSF) and Stanford University installed a prototype Automatic Weather Station (AWS) at Marble Point, Antarctica, on 15 January 1976; see Figure 2-9. The AWS transmitted weather and operational data to the NIMBUS F satellite for readout in the USA. A Navy URIPS-8 RTG provided more than eight watts of continuous power during the operational life of the station; see Figure 2-10.

The AWS functioned perfectly for more than six months. Then, on 20 July 1976, the weather sensor data as received were unusable. The data continued to come in unusable until 5 May 1977 when transmissions from this AWS ceased. The nature of unusable data received prior to total failure of the station tended to indicate that the failure was in the AWS equipment.

On 13 October 1977, a team visited the site and inspected the station, no physical damage was found. On 30 October 1977, the AWS and the RTG were recovered by helicopter and returned to McMurdo Station for storage. The RTG was still operating normally. The electronics package from the AWS was returned to Stanford University for evaluation; the electronics failure was traced to the failure of two integrated circuits which control the timing of the RF transmitter circuits.

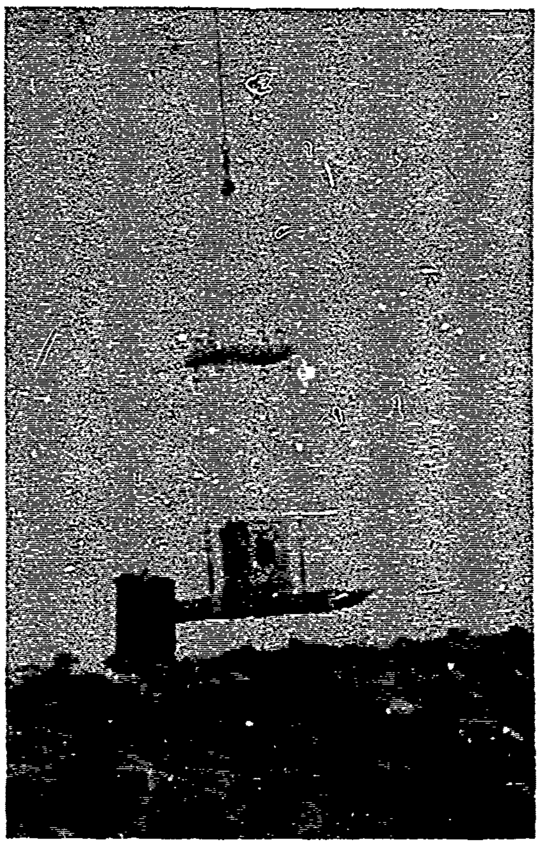


**Figure 2-9. RTG (in Shipping Container) on Special Sled Being Lowered by Helicopter to Marble Point Site.**

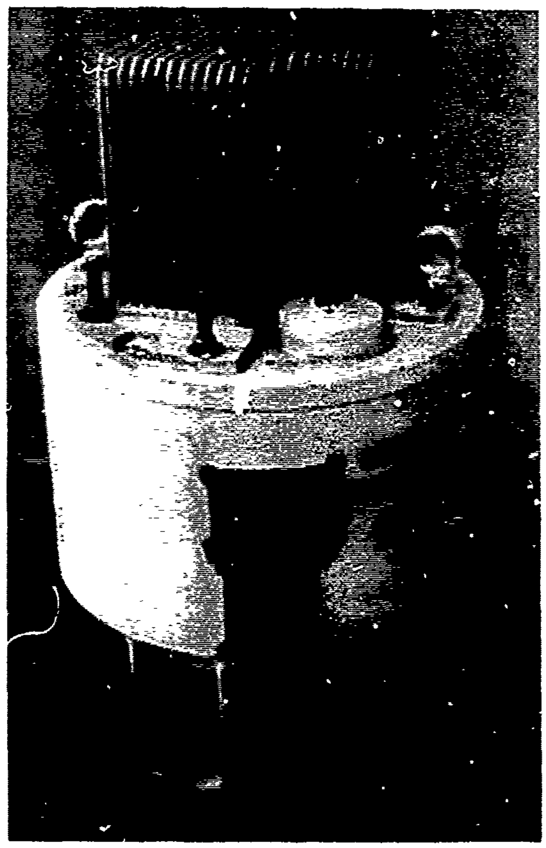


**Figure 2-10. URIPS-8 RTG.**

This same RTG-powered AWS operated successfully at the South Pole (Figure 2-11) from 20 January 1975 to 7 December 1975 when it was moved to McMurdo Station for redeployment to Marble Point. This earlier success, and the complete reliability of the RTG throughout the Marble Point deployment has again proven the suitability of RTGs for remote polar operations. As a result, plans are in process for deploying seven advanced model AWSs in Antarctica during the 1978-1979 Austral Summer. Tentatively, five of these stations will be located in the McMurdo area and two at Byrd Station. The five AWSs in the McMurdo area will include one at Marble Point and one at Minna Bluff. Besides the URIPS-8 RTG which is now in storage at McMurdo, six additional RTGs will be deployed to Antarctica to power these new AWSs; these six additional RTGs will include three 8-watt URIPS-8 RTGs and three 10-watt SNAP-21 RTGs.

**2.2.2.3 RTG Powers Polar Automatic Weather Station at Minna Bluff, Antarctica.** In December 1975, the National Science Foundation and the Naval Research Laboratory shipped a prototype Polar Automatic Weather Station (PAWS) and related RTG to Antarctica; see Figure 2-12. Due to shipping delays enroute, the PAWS and RTG arrived too late for local deployment during that Austral Summer, both were subsequently stored temporarily at McMurdo Station.

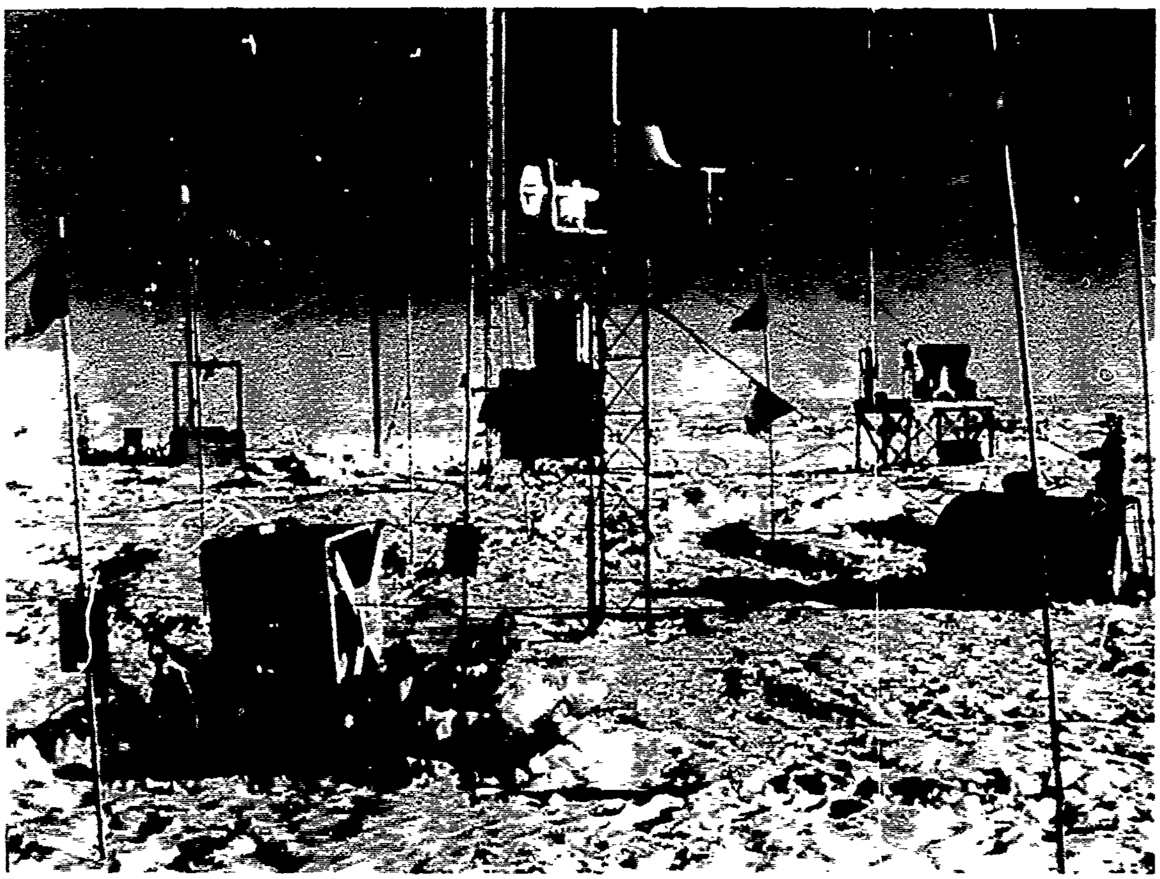


**Figure 2-11. RTG-Powered Automatic Weather Station at South Pole.**

Figure 2-12. Polar Automatic Weather Station.

The prototype PAWS, with a Navy 25-watt Sentinel-25F RTG installed (Figure 2-13), was transported by helicopter to Minna Bluff on 26 December 1976. The RTG was operating satisfactorily, but the PAWS system was inoperative after the implant. The PAWS system also suffered storm damage during the period 7 – 9 January 1977. After field repairs were unsuccessful in rendering the PAWS system operational, the system with RTG was recovered and returned to McMurdo Station on 20 January 1977. The 25-watt RTG was still operating normally and was returned to the RTG Surveillance Facility at Point Mugu, California, in March 1978. Plans are in process for placement of a different type of RTG-powered automatic weather station at Minna Bluff during the 1978 – 1979 Austral Summer (see paragraph 2.2.2.2).

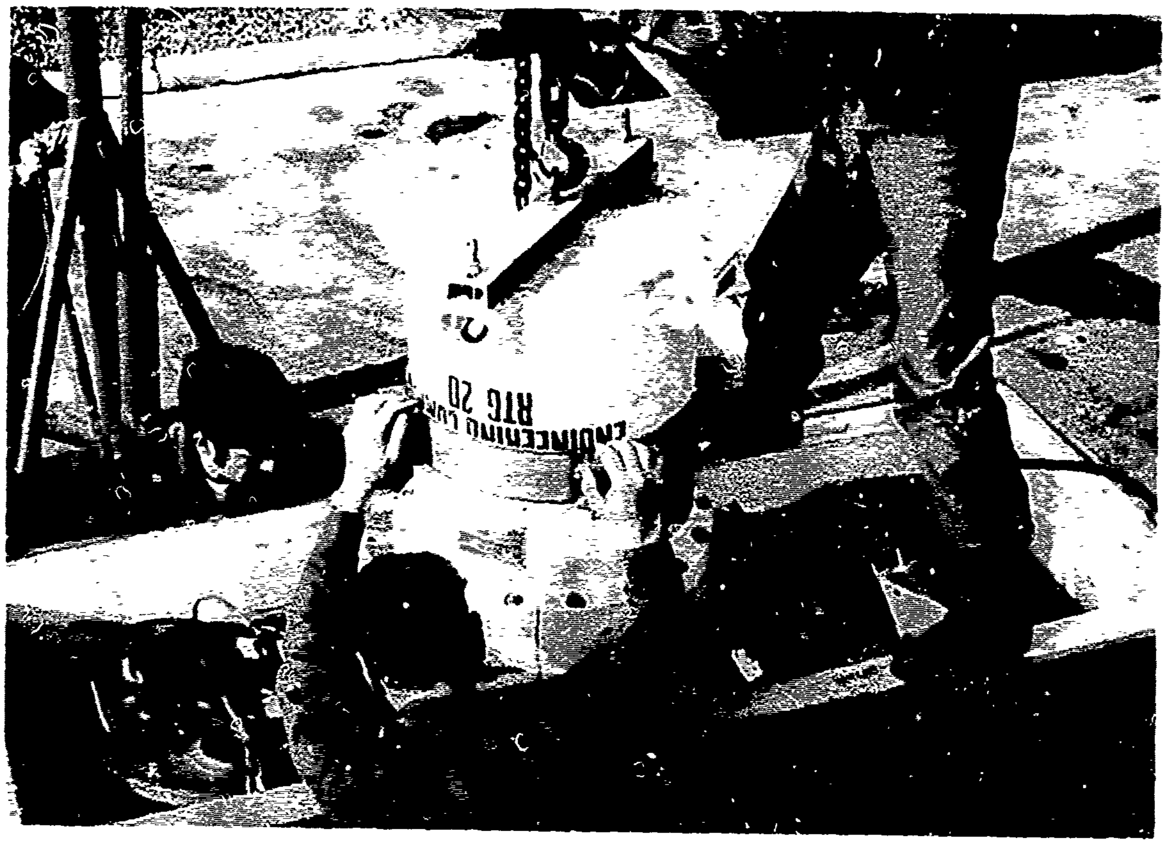


**Figure 2-13. Sentinel-25F RTG Being Integrated with PAWS System.**

## 2.2.3 UNDERSEA MISSIONS

**2.2.3.1 RTG Provides Power for Undersea Structure off California Coast.** A 10 watt SNAP 21 RTG was installed in 2900 feet of water in the Santa Monica Basin on 29 August 1974, in support of the SEACON II project. The Navy's Civil Engineering Laboratory built an undersea experimental three-legged cable structure a half mile high and more than a mile wide to evaluate structure response to changing ocean currents; see Figure 2-14. Two of the three mooring legs were secured to the sea floor by deep water explosive embedment anchors. The third leg was secured by an 8-ton dead weight clump anchor which also doubled as a container for the RTG and a 48-volt lead-acid backup battery.

The main source of data on structure response was an acoustic positioning system consisting of acoustic projectors on the sea floor and hydrophones at key locations on the structure. Sensors for measuring cable tensions and water depths at key locations completed the structure response measurement system. All sensors were controlled and data were recorded on magnetic tape by an electronics package located in a crown buoy 50 feet below the ocean surface. A current measurement system detected the magnitude and direction of the ocean currents which moved the structure about.

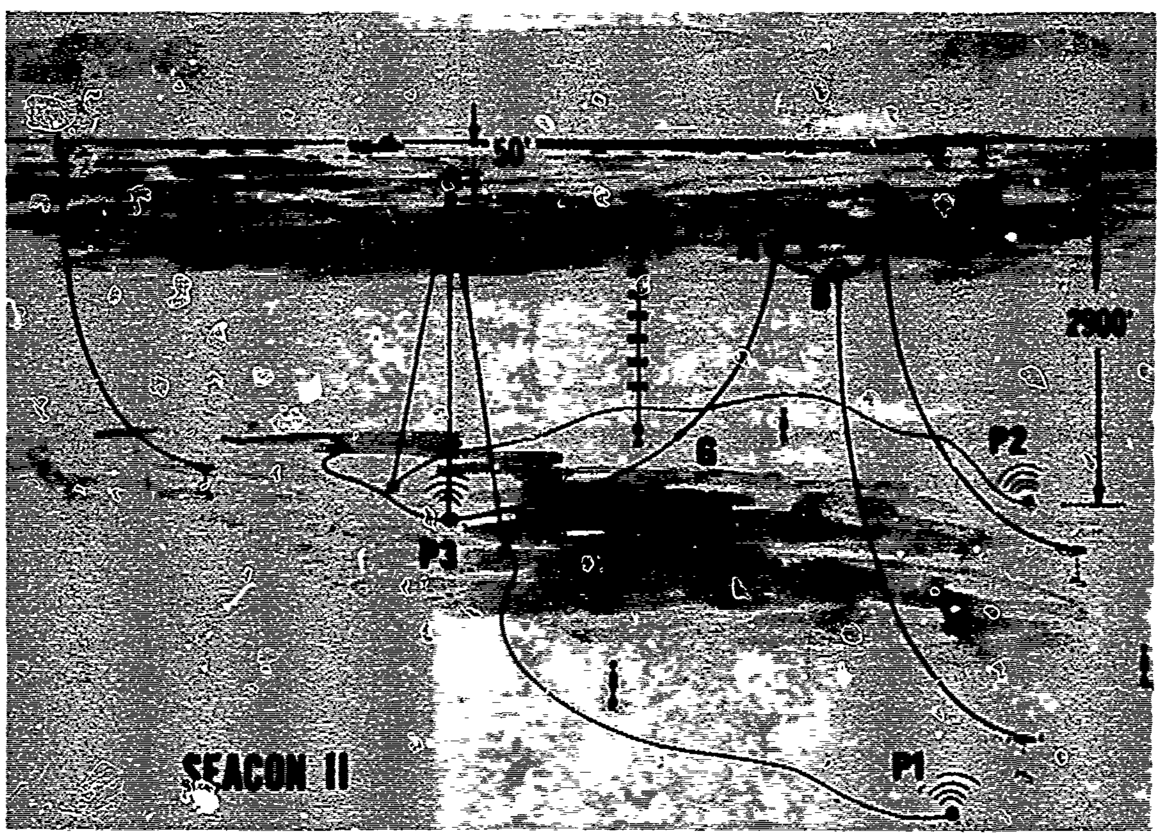



**Figure 2-14. General Plan of SEACON II System.**

The success of the project depended upon reliable power for the sensors and data recording system. The selected power system combined the use of central and distributed energy elements as shown in Figure 2-15. The central power unit consisted of a SNAP-21 RTG, see Figure 2-16. The RTG provided 12.5 watts of raw power at 4.99 volts; this was DC-DC converted to 48 volts to operate the three acoustic projectors and to trickle-charge the nickel-cadmium battery pack used to operate the electronic equipment in the crown buoy. Each of the seven distributed electronic packages on the structure was powered with non-rechargeable primary mercury battery packs.

After almost two years of successful operation and achievement of project objectives, the SEACON II project was terminated and the RTG was recovered on 22 July 1976. This project showed that RTGs are reliable power sources for remote undersea operations.

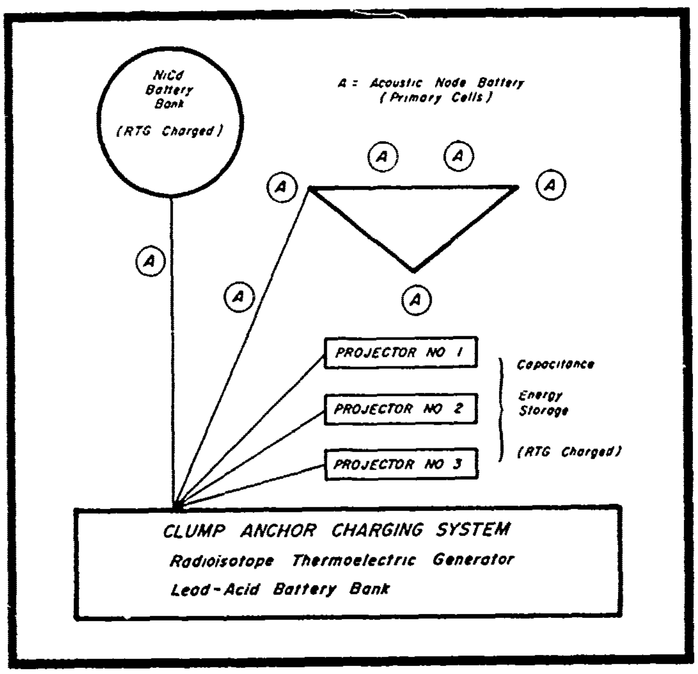



**Figure 2-15. SEACON II Power System.**

**Figure 2-16. SNAP-21 RTG Used in SEACON II System.**

**2.2.3.2 RTG Powers Undersea Experiment on Pacific Seamount.** A 25-watt Sentinel-25C1 RTG (formerly designated LCG-25C1). was installed 3 June 1969 at a depth of 2200 feet on the San Juan Seamount, 180 miles WNW of San Diego. The RTG (Figure 2-17) provided power for an Inter-Seamount Acoustic Range (ISAR) transmitter consisting of a string of acoustic projectors used for sending periodic acoustic pulses over a long deep-water path to a receiver facility located 190 miles distant at the Westfall Seamount.

The system operated satisfactorily and the experiment was completed in 1973. The acoustic system continued to operate satisfactorily for approximately 5.6 years; system failure was reported 31 January 1975.

Recovery of the system was made difficult because of earlier events which took place during deployment of the system. Unknown factors caused premature firing of acoustic release mechanisms while the recovery system was still on board the deployment vessel, this resulted in deletion of the acoustic release mechanisms and related parts of the recovery system. Two attempts to recover the system in the summer of 1973 were aborted due to weather and recovery vehicle problems. Recovery attempts during July 1974 were unsuccessful and were aborted due to weather. No recovery attempts were made in 1975. Recovery of the system and the RTG was finally effected 28 April 1976. This five year design life RTG was still operating normally after almost seven years submersion at a depth of 2200 feet.

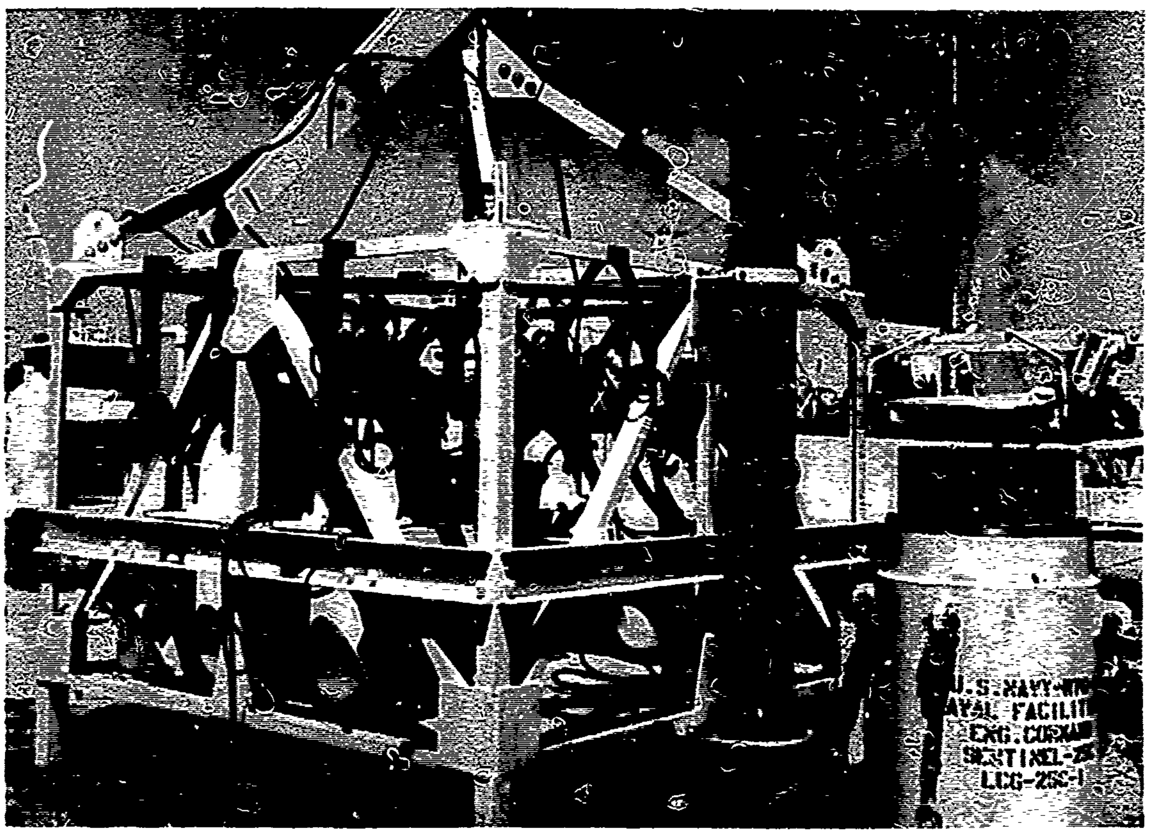


**Figure 2-17. Sentinel-25C1 RTG Standing Beside Platform on Which it was Mounted for Mission.**

Figure 2-18. Millibatt-1000 RTGs.

**2.2.3.3 RTGs Power Deep Ocean Transponder Systems on Air Force Eastern Test Ra**[illegible] On 27 February and 1 March 1977, two Millibatt-1000 RTGs were installed on the Air Force Eastern Test Range (AFETR) located in the South Atlantic; see Figure 2-18. These ten-year design life RTGs had been mated with deep ocean transponder systems designed to serve along with existing transponder systems as permanent geodetic refere[illegible] AFETR missile impact location arrays. Figure 2-19 shows one of the RTGs with the transponder system ready for launching. Unfortunately this system failed to respond to interrogation shortly after implant. An analysis of the implant showed that the free-falling RTG-powered system descended at a velocity greater than previously calculated, and failed because of excessive deceleration when it impacted on the ocean bottom at a depth of about 10,500 feet.

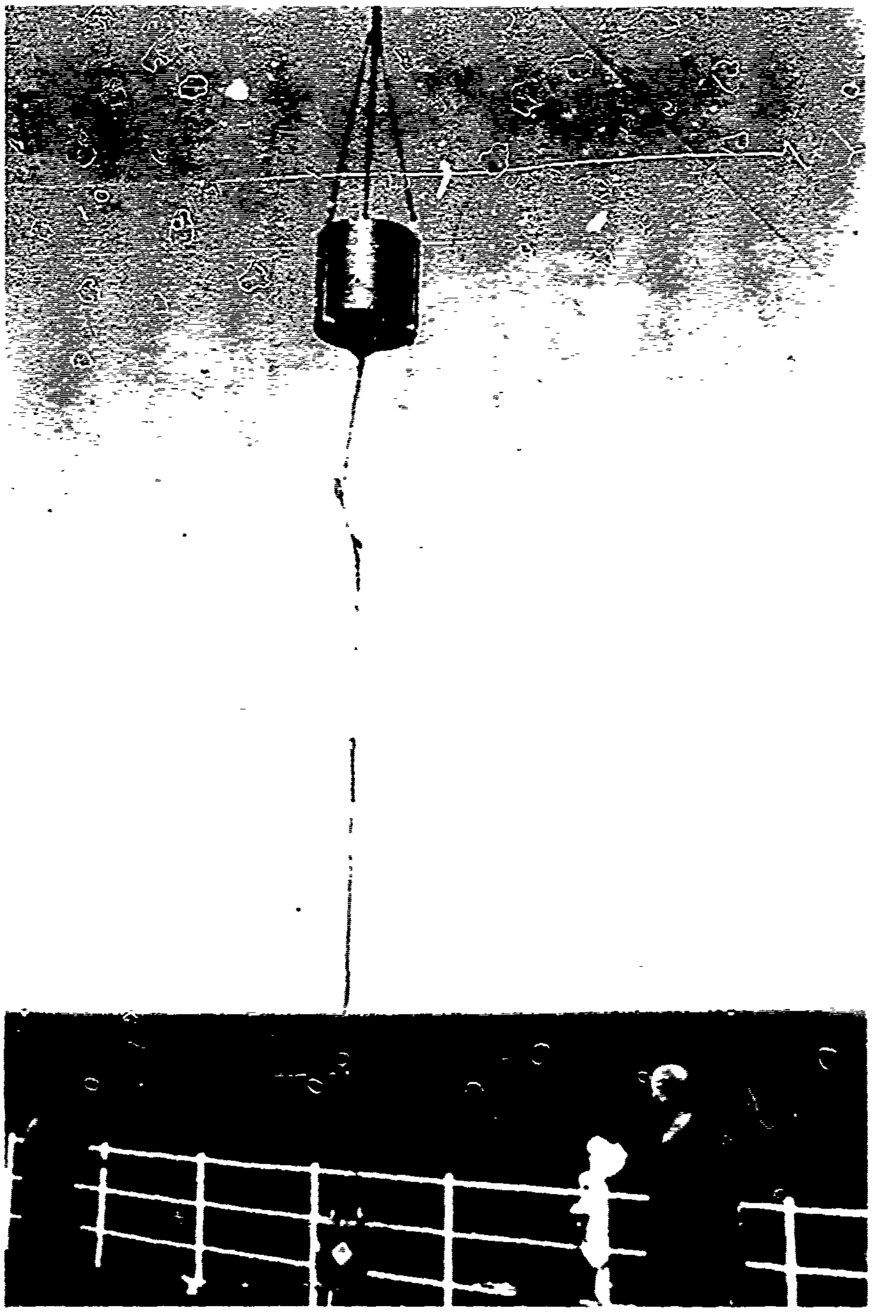


**Figure 2-19. Millibatt-1000 RTG and Deep Ocean Transponder System Ready for Launching.**

The second system was modified to eliminate this problem. After implantment, this system responded successfully, but exhibited an abnormal directional pattern with operating ranges unacceptably low in certain azimuths and higher than normal in other azimuths. Its abnormal directional pattern is believed to be related to the transponder or to failure in the connecting sling/bridle assembly between the transponder and RTG rather than to the RTG itself; see Figure 2-20. Because of these problems, plans for implanting four additional RTG-powered systems during the same mission were cancelled.

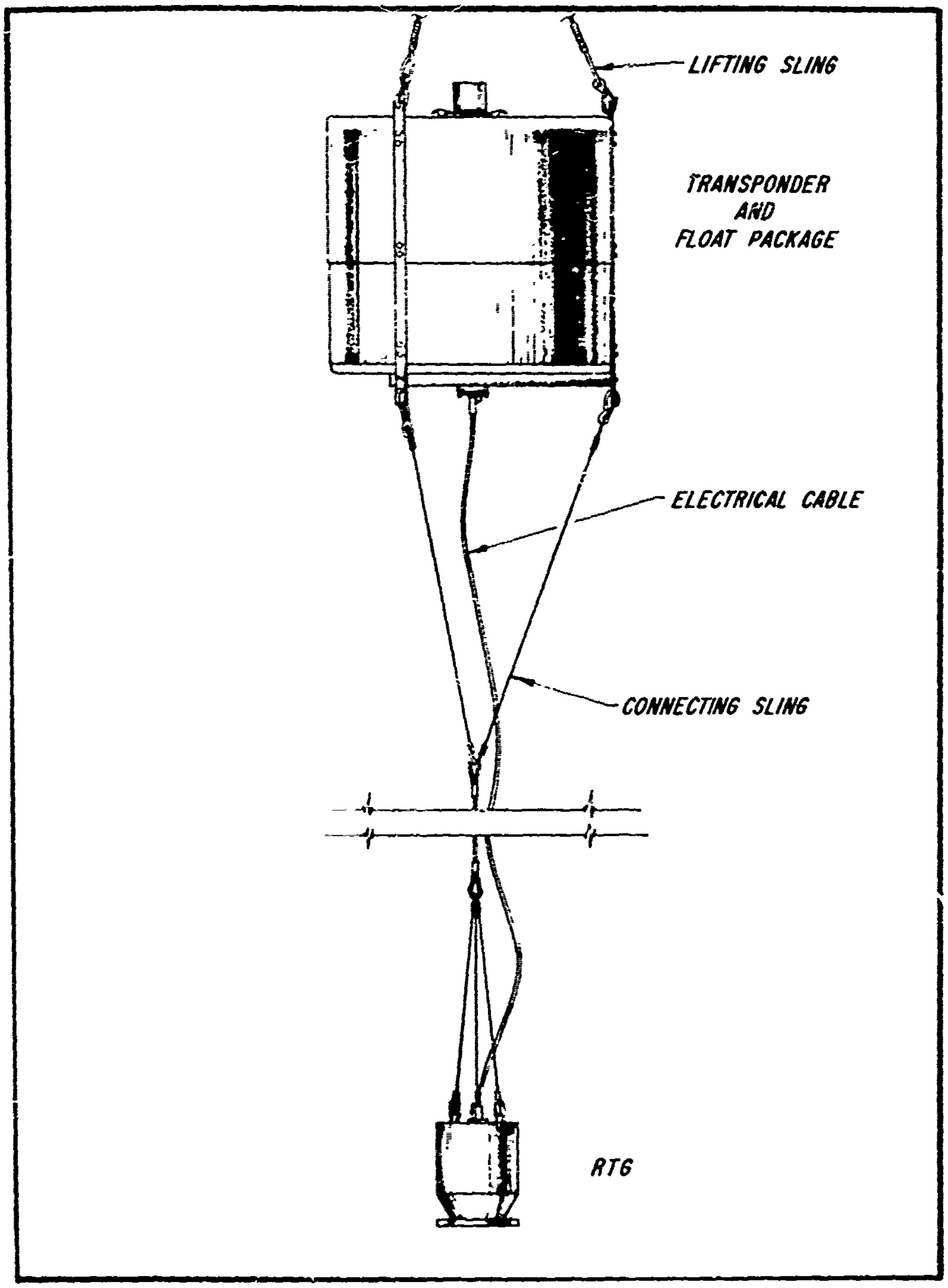



Figure 2-20. Deep Ocean Transponder System.

## 2.2.4 SEA SURFACE MISSIONS.

**2.2.4.1 RTGs Power Wave Gage System in Gulf of Mexico.** Three Sentinel-25D RTGs were installed on a Texas-Tower-type platform known as the Stage I Tower located approximately 11.25 miles off-shore from Panama City Beach, Florida, on 22 June 1973; Figure 2-21 shows the Stage I Tower. The RTGs power an array of surface wave gages and a microwave telemetering system for transmitting wave data from the tower to shore; on shore the data are subjected to computer analysis and used for operational planning purposes by the Naval Coastal Systems Center, Panama City, Florida.

In this mission three RTGs were placed in series in order to provide the 60 watts of conditioned power required; see Figure 2-22. The 2.9 – 3.0 volt output of the RTG is DC-DC converted to voltages required by the wave gages and telemetry equipment. These 5-year design life RTGs are now more than eight years old and are performing reliably. This project has shown the feasibility of connecting compatible RTGs in series to meet a power requirement for which a single RTG is inadequate; it has also shown that RTGs are reliable power sources for remote sea surface missions.

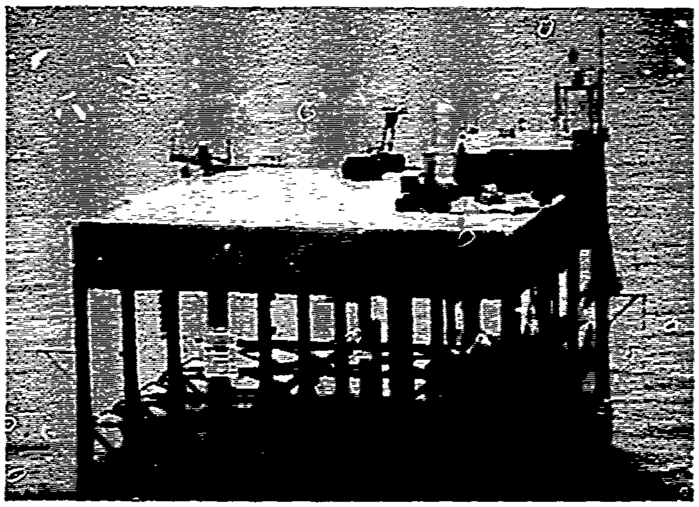


**Figure 2-21. Stage I Tower in Gulf of Mexico.**

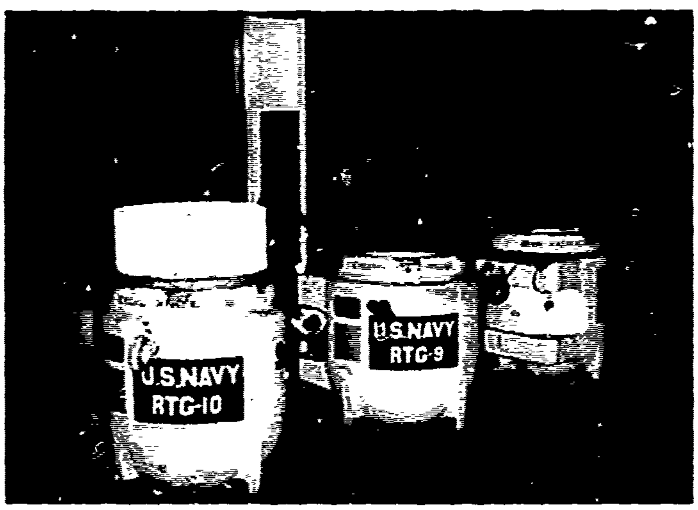



**Figure 2-22. Three Sentinel-25D RTGs Electrically Connected in Series.**

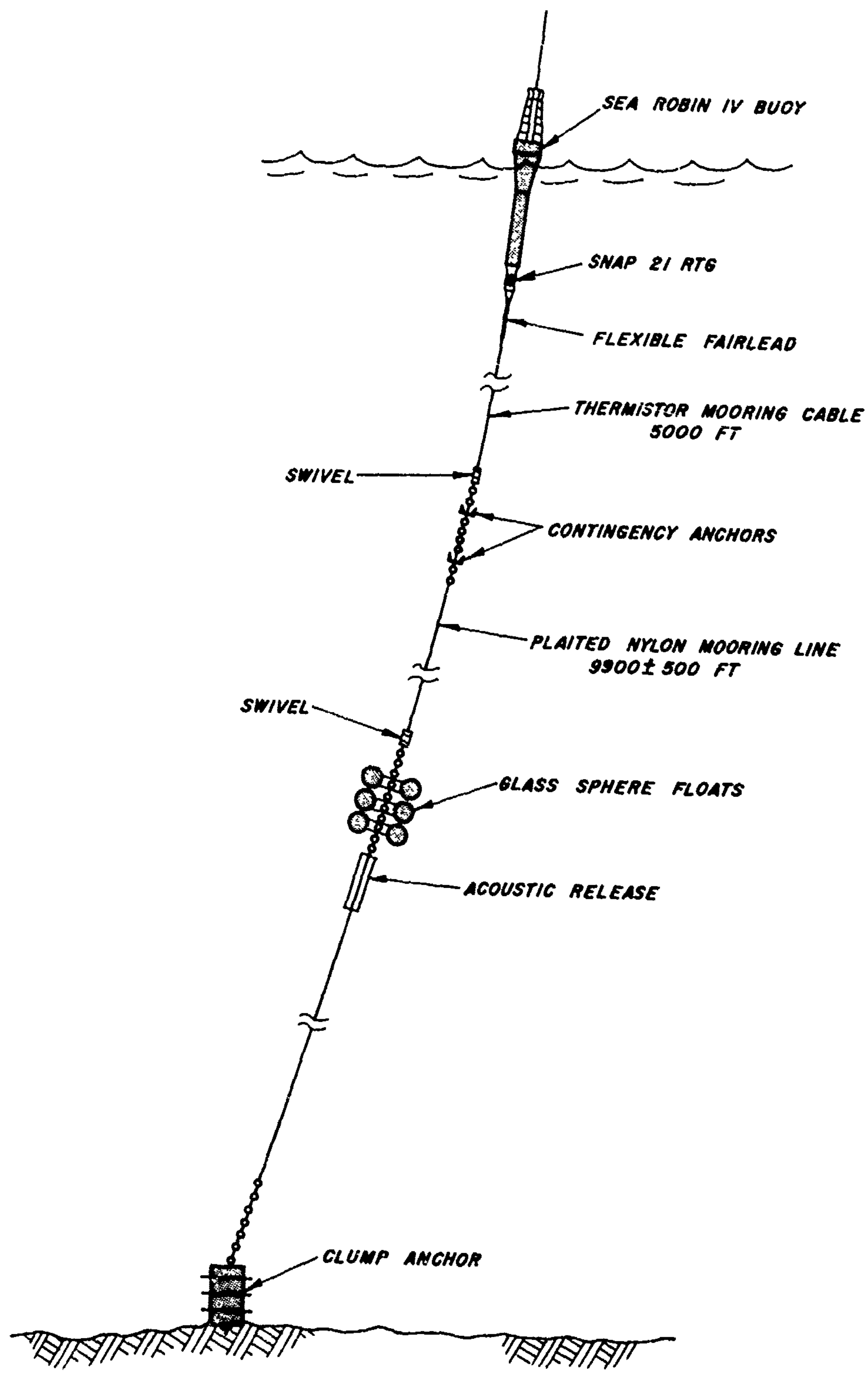



Figure 2-23. SEA ROBIN IV Buoy and Mooring Configuration.

**2.2.4.2 RTG Powers Spar-Type Data Buoy off Bahamas.** A 10-watt SNAP-21 RTG on a spar-type data buoy system (SEA ROBIN IV) was successfully installed with deep ocean mooring east of Eleuthera Island, Bahamas, on 15 January 1976; see Figures 2-23 and 2-24. The RTG provided about 13 watts of power at a raw output voltage of 4.96 volts; this was DC-DC converted to the 24 volts required by the telemetry system and to other voltages for other elements of the system. The RTG continuously charged auxiliary nickel-cadmium battery packs which provided 12V and 28V power for periodic peak loads and emergency power for limited operation in the event of RTG failure.

The system performance was satisfactory until 17 March 1976, when the buoy and the mooring system separated, communication with the buoy was lost, and the buoy was adrift. After commercial ship sightings of the buoy on 20 March, no further sightings were reported until 28 March when a Navy P-3 search aircraft made radar contact. Ship control of the buoy was regained on 28 March, and the buoy with RTG was recovered on 29 March 1976. Failure of the mooring was determined to be the result of inadequate design and faulty construction of the cantilevered fairlead interface between the buoy and the mooring. RTG performance and reliability were not affected. This project showed that an RTG is a satisfactory power source for a surface buoy, but extreme care must be exercised in designing and manufacturing the buoy mooring system.

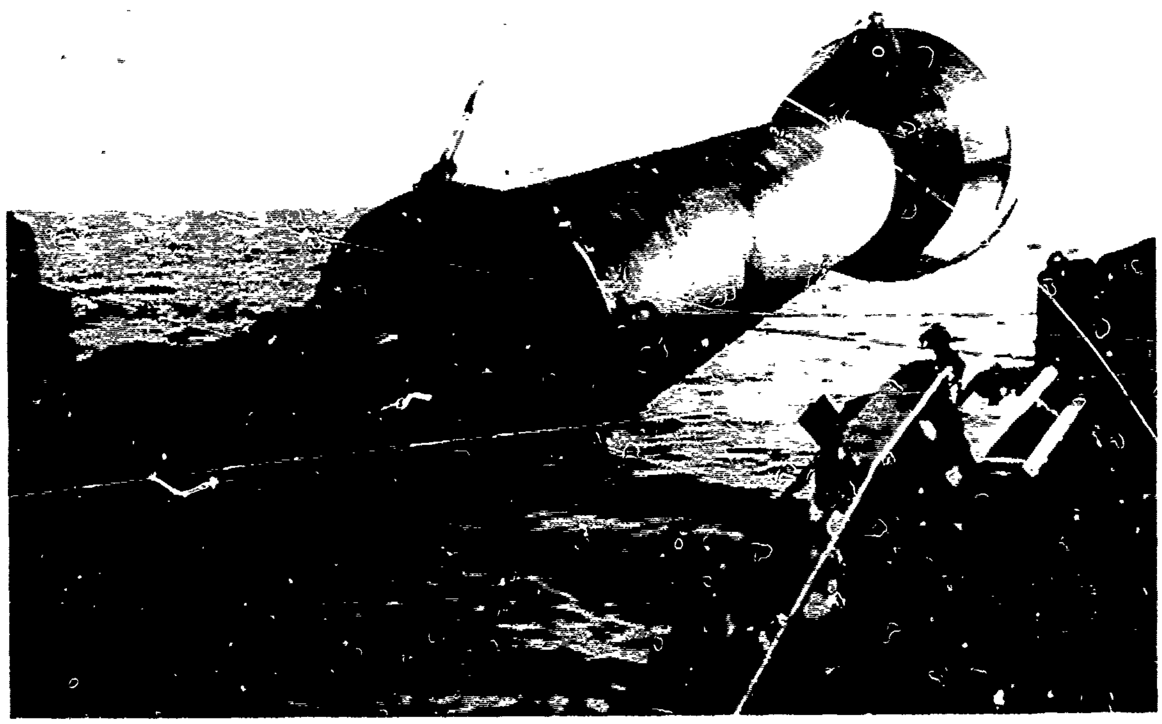


**Figure 2-24. SEA ROBIN IV Buoy Being Lowered Into Water During Deployment; RTG is in Cage at Left End of Buoy.**

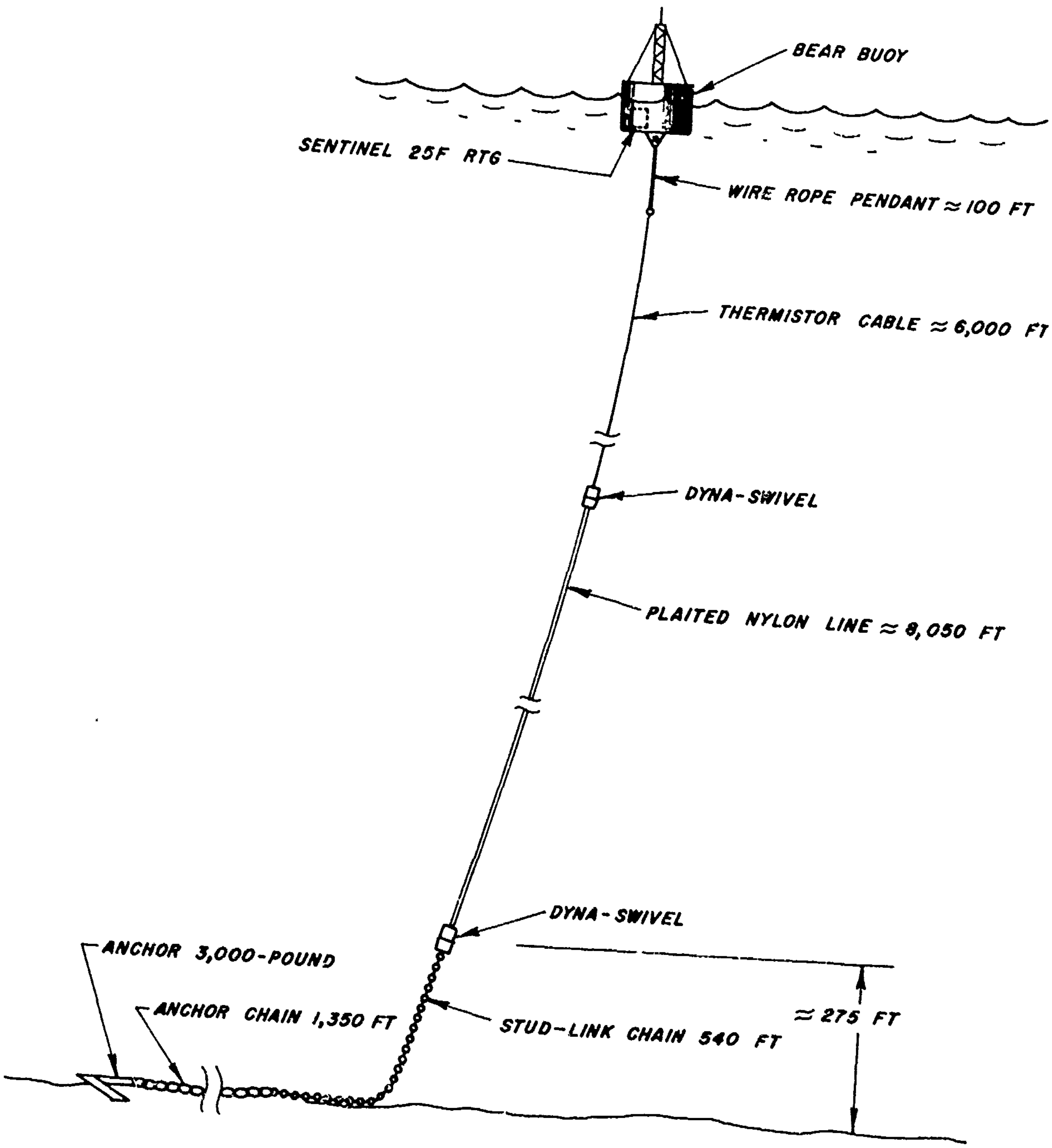



Figure 2-25. BEAR Buoy and Mooring Configuration.

2.2.4.3 **RTG Powers Drum-Type Data Buoy off Bahamas.** A 25-watt Sentinel-25F RTG on a drum-type data buoy system (BEAR Buoy) was successfully installed with a deep ocean mooring east of Eleuthera Island, Bahamas, on 12 February 1976, see Figures 2-25 and 2-26. The RTG (Figure 2-27) provided about 32.9 watts of power at a raw output voltage of 2.79 volts, this was DC-DC converted to the 30 – 32 volts needed to continuously charge a 28-volt lead-acid battery pack which provided direct power for the telemetry system.

The system performance was satisfactory until 7 May 1976, when the telemetered data from the buoy were garbled. The problem was erroneously assumed to be in the system on board the buoy (it was later found to have been in the land-based receiving station), and after unsuccessful attempts to solve the assumed electronics/communications problem remotely, the RTG and electronics capsule were removed from the buoy and returned to Miami, Florida, on 28 May 1976 for test and repair of the electronics. RTG performances and reliability were not affected.

Due to various factors the RTG and electronics were not reinstalled on the buoy which remained on station. In August 1976 the buoy was subjected to the forces of 20 to 30 foot waves and 60 – 75 knot winds during Hurricane Belle. The upper 30 feet of mooring cable and termination fittings were inspected by a diver on 3 December 1976 and found to be in good condition. Sometime later, probably in the middle to end of January 1977, the mooring broke in the thermistor cable at a distance of about 800 – 1200 feet below the buoy. The drifting buoy was taken under tow about two or three weeks later, and was towed into port on Andros Island.

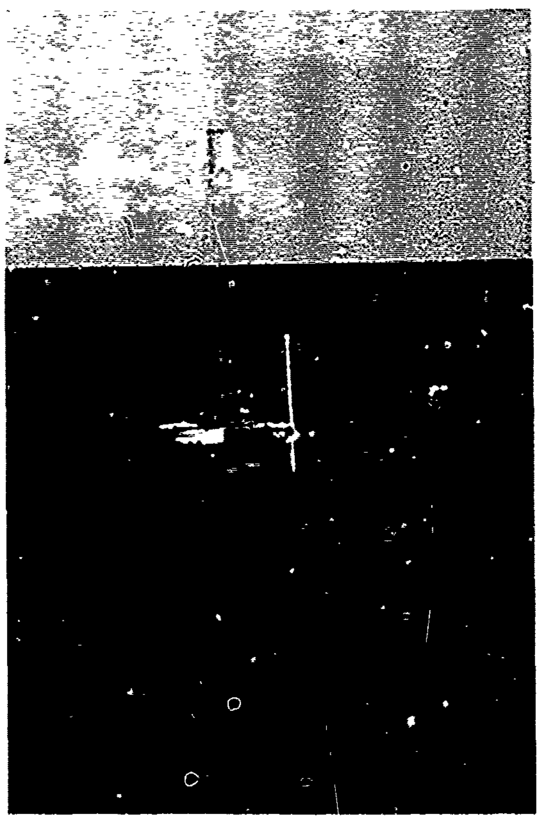


**Figure 2-26. The BEAR Buoy Deployed.**



**Figure 2-27. Sentinel-25F RTG.**

2.2.5 OTHER TERRESTRIAL MISSIONS.

**2.2.5.1 RTG Provides No-Break Power Source for Data Systems in Bahamas.** The Navy's highest powered RTG, a 100-watt Sentinel-100F was successfully installed at the Naval Facility on Eleuthera Island, Bahamas, on 13 December 1974; see Figures 2-28 and 2-29. The RTG provides about 125 watts of raw power at 9 volts; this is DC-DC converted to 24V to provide a no-break power source for a quartz crystal clock timing system for the shore-based data acquisition system. The data system supports Office of Naval Research programs on the Bermuda-Eleuthera Acoustical Range.

This five-year design life RTG (Figure 2-30) has been providing power continuously for more than three years. Plans are presently in process to move this RTG to an undersea habitat experiment near St. Croix, Virgin Islands, in the summer of 1978. where it will serve as an emergency power supply for life-support equipment.

**Figure 2-28. Sentinel-100F RTG Being Lowered Into Concrete Lined Well Adjacent to Communications Building.**

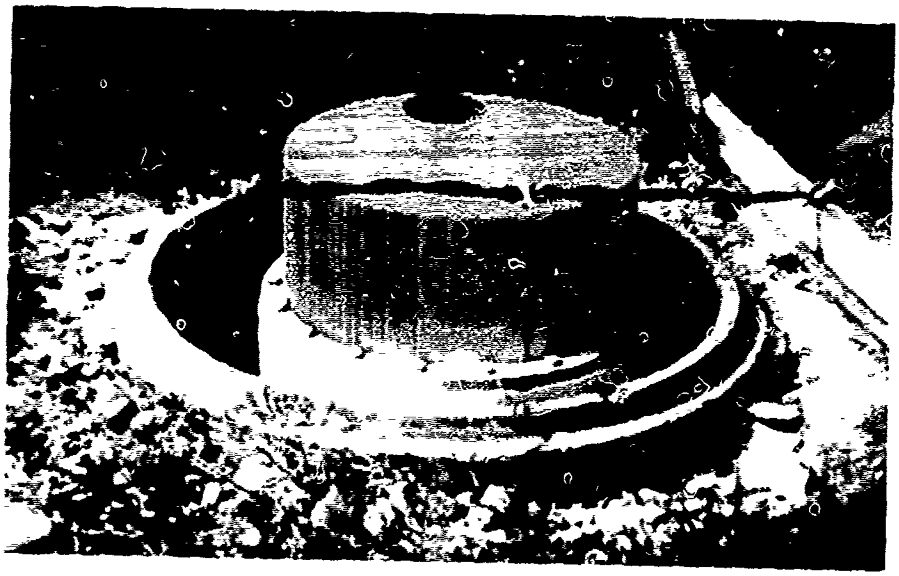


Figure 2-29. Sentinel-100F RTG After Three Years of Operation.

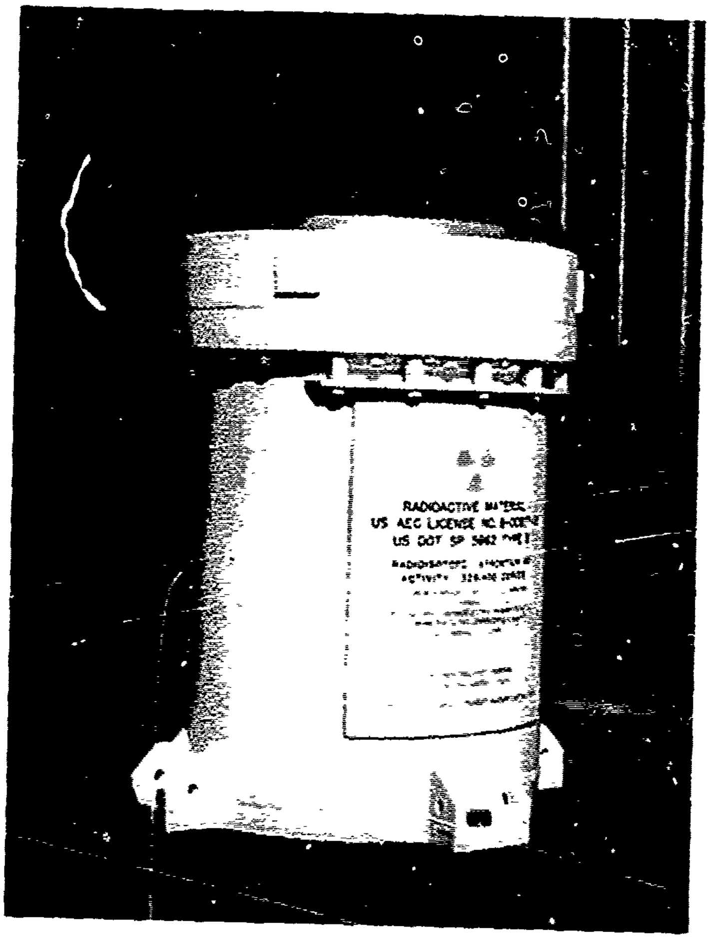


Figure 2-30. Sentinel-100F RTG.

2.2.5.2 **RTG Powers Automatic Meteorological Data Collection Station.** An 8-watt Sentinel-8 RTG was successfully installed at a site 794 feet above sea level on San Miguel Island off the coast of California on 20 November 1970; see Figures 2-31 and 2-32. The RTG continuously charges a 15-volt nickel-cadmium battery which provides power for the meteorological data collection system; the data are transmitted to Naval Air Station, Point Mugu, California, for use in Pacific Missile Test Center operations.

The location of the system and RTG on the island was changed once in 1976. There have been several failures of batteries and electronics during the seven years of operations, but the five-year design life RTG has performed reliably throughout that period.

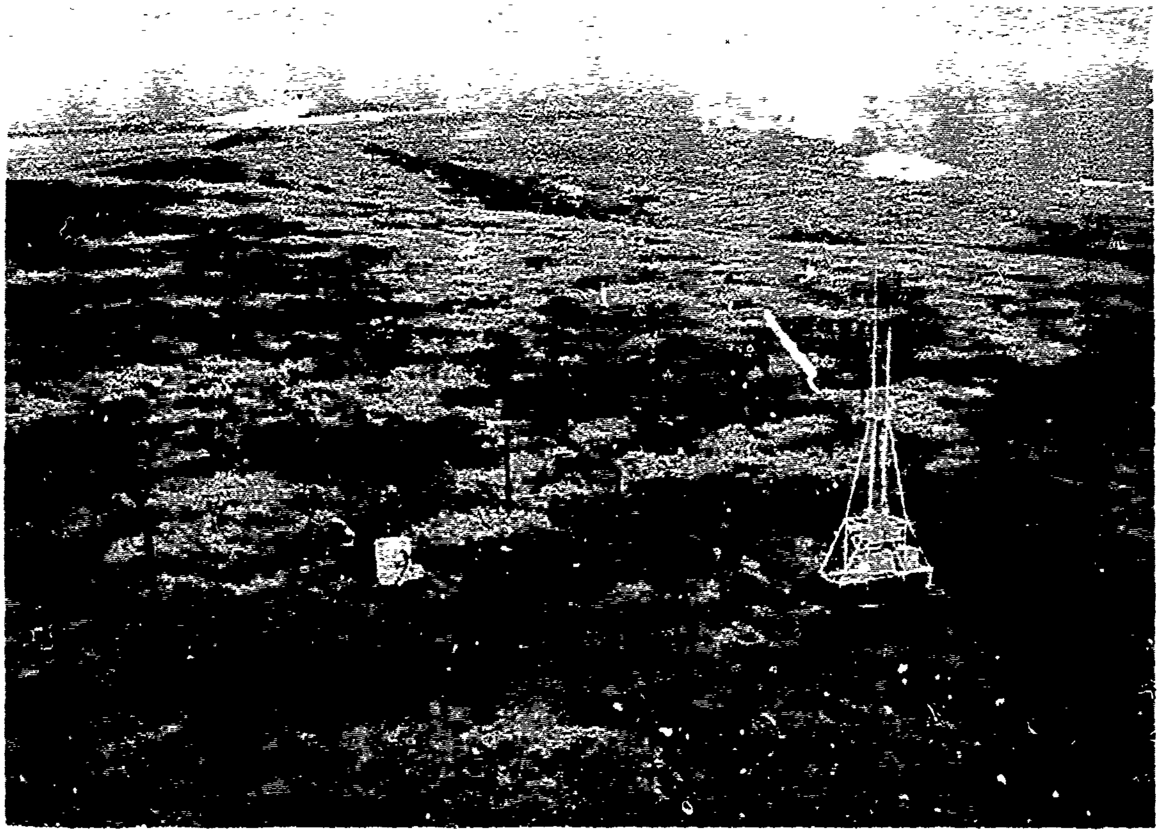


**Figure 2-31. Air View of RTG-Powered Meteorological Station on San Miguel Island.**

Figure 2-32. Sentinel-8 RTG in Foreground With Meteorological Station in Background.

2.2.5.3 **RTG Provides Power for Experimental Research and Development Projects.** One of the Navy's oldest RTGs, a SNAP-7E, was installed at the Naval Avionics Center, Indianapolis, Indiana, on 12 November 1970; see Figure 2-33. This RTG provides about three watts of electrical power for testing low-powered experimental weather stations, telemetry systems, and electronic components. The RTG performance has been reliable throughout the past seven years of operation.


**Figure 2-33. Checking SNAP-7E RTG for Radiation Level After Unloading at Naval Avionics Center, Indianapolis.**

## 2.3 FUTURE APPLICATIONS.

**2.3.1 EFFECTS OF TRENDS IN ELECTRONICS.** Improvements in integrated circuits and miniaturization of components has resulted in more compact electronics with reduced power requirements. Because RTGs are essentially low-power devices, the RTGs are now able to meet the power requirements of a wider range of electronic systems, and the miniature electronic systems are finding a wider range of applications. Thus RTGs are becoming qualified for an increasing number of potential applications.

Likewise, the number of communications satellites is increasing; this reduces the power requirements for communications stations which can transmit directly to such satellites. This makes transmitting stations (meteorological and seismic sensoring) more attractive for coverage of remote areas; RTGs are ideal for powering such sensors and transmitters.

New developments in fiber optics have opened new fields of activity in the area of communications cables. The requirements for repeater stations has generated increased interest in RTGs as possible power sources for remote applications.

**2.3.2 EFFECTS OF TRENDS IN RTGs.** All of the present applications of RTGs described in paragraph 2.2 above have involved the use of RTGs using strontium-90 as the radioactive fuel for the heat source. Strontium-90 requires considerable biological shielding material in the RTG; this, together with a pressure hull for undersea applications, gives the RTG substantial bulk and weight. The Navy is presently testing RTGs fueled with plutonium-238, which, in small quantities, does not require shielding; see Chapter Three. This permits the construction of RTGs of relatively small size and makes them more attractive where small size, low weight, and ease of handling are essential to an application. The availability of these small RTGs has stimulated interest in the use of RTGs in cables and small electronic systems.

## CHAPTER THREE
## THE NAVY SUPERBATTERY

### 3.1 GENERAL DESCRIPTION.

3.1.1 CHARACTERISTICS. The Navy superbattery is a half-watt RTG using a heat source fueled with plutonium-238. In configuration the RTG is a right circular cylinder about 2 inches in diameter and from 5 to 6 inches long; this is about the size of a conventional two-cell flashlight; see Figure 3-1. Functionally, the generator, when connected to a fixed resistive electrical load of about 85 ohms, provides a minimum power output of 0.5 watt for a minimum period of 15 years. The voltage throughout the life of the generator is designed to be in the range of 6.0 to 8.5 volts, with 8.0 volts being a desired maximum. This equates to 65,700 watt-hours of electricity over the 15-year life of the RTG. This is as much power as would be produced by standard lead-acid automobile batteries weighing about 3.5 tons. Considering that the weight of each RTG is about two pounds, the energy density of the RTG computes to 32,850 watt-hours per pound.

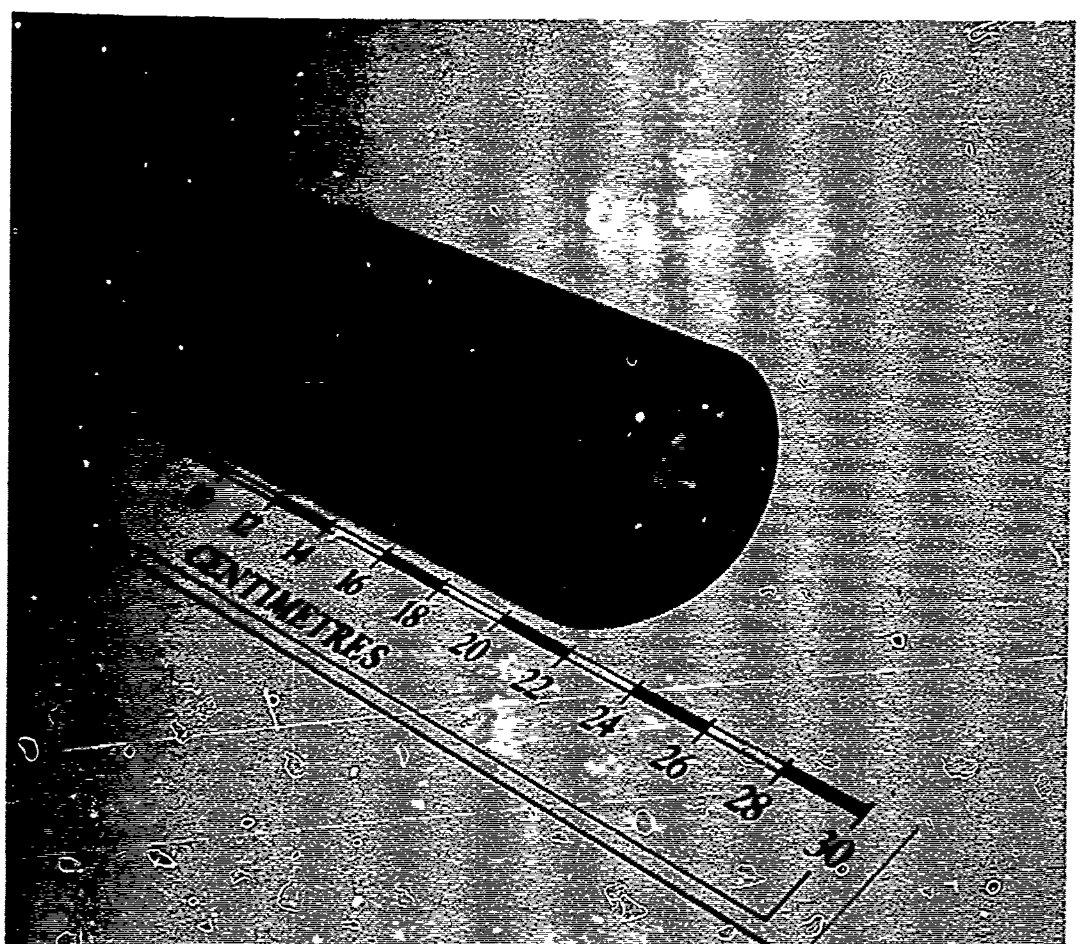



Figure 3-1. Typical Half-Watt RTG

3.1.2 DESIGN. In principle, the half-watt RTG is a rather simple electrical device; see Figure 3-2. The heart of the device consists of a thermoelectric converter, a plutonium-fueled heat source which keeps one side of the converter hot, and an outer case which functions as a container and provides the heat sink to keep the other side of the converter cool. Two electrical leads conduct the DC electricity out of the converter, and thermal insulation helps to confine the flow of heat through the thermoelectric converter. An adapter stabilizes the heat source alignment and presses the heat source against the thermoelectric converter. The pressure plate distributes the spring pressure over the end surface of the adapter. The spring provides the force which maintains pressure between the heat source and thermoelectric converter and between the thermoelectric converter and the heat sink. The plug provides access to the interior of the RTG for evacuation and for backfilling with gas.

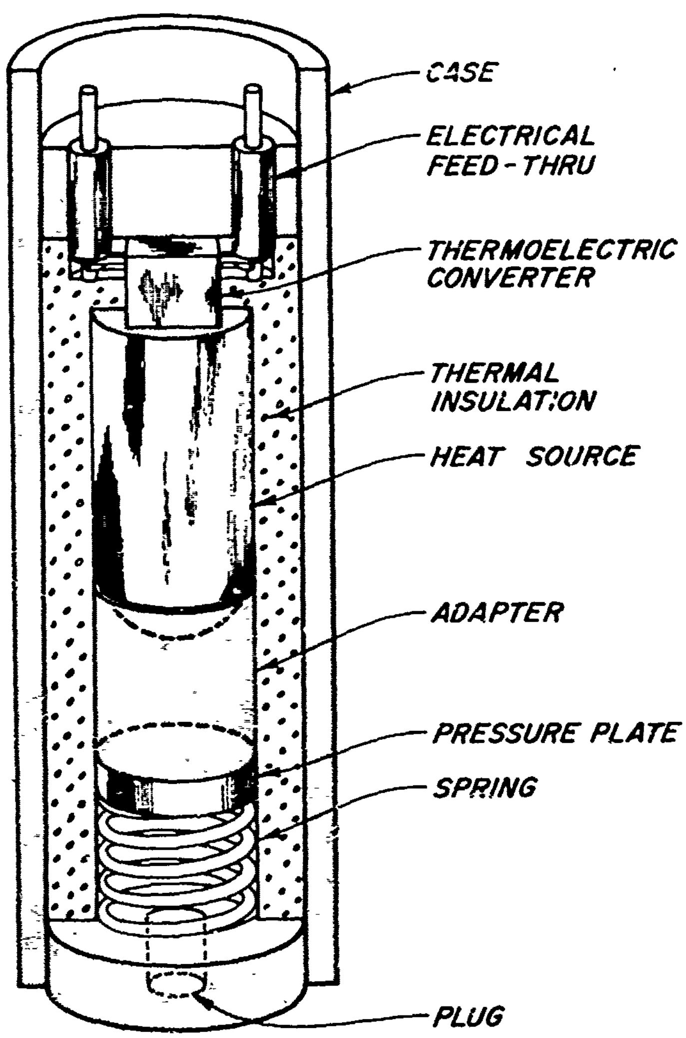



Figure 3-2. Cutaway View of Half-Watt RTG

## 3.2 APPLICATIONS.

**3.2.1 POTENTIAL USES.** The Navy superbattery was originally procured as a special-purpose power source for use in cables in undersea surveillance systems. As procurement progressed, it became obvious that this design is suitable for any use where small, long-life, distributed or point power sources of high reliability are required. Numerous potential applications of this power source are anticipated, such as in fiber-optic cables, remote point sensors (meteorological, seismic, and other), remote communications stations, and navigation beacons.

**3.2.2 DESIGN FLEXIBILITY.** Potential users of the superbattery need not be constrained by its size or its output power characteristics, as both can be tailored to fit the requirements of supported systems. Studies have shown that a half-watt superbattery using the present heat source design could be constructed with a minimum diameter as small as 1.6 inches and a minimum length of 4 inches. For power requirements less than one-half watt, further reductions in size would be possible with a new heat source design.

For power requirements greater than one-half watt, present units could be used in multiples. By increasing size somewhat, the output power of a single RTG could be increased to several watts.

For voltage requirements greater than 6 to 8 volts, supported systems can provide power conditioning in their circuitry. By changing the design of the thermoelectric converter, direct output voltages as high as 20 – 24 volts are believed to be attainable without the use of any power conditioning equipment.

# CHAPTER FOUR

# RADIOISOTOPE THERMOELECTRIC GENERATOR INVENTORY AND TECHNICAL SPECIFICATIONS

**4.1 INTRODUCTION.** This chapter summarizes the electrical and physical characteristics of RTGs in the Navy's inventory. RTGs are grouped by model and models are arranged alphabetically.

Whenever possible, two pages have been devoted to each RTG model. The first page contains pertinent physical characteristics and a sketch of the model. The facing page presents electrical performance data and fueling information typical of all RTGs of that model. The plot of voltage versus equilibrium current results from a quadratic least squares fit of the illustrated data points. The smooth plot of power versus equilibrium current was then obtained by multiplying the equation for the voltage versus current curve by current. Located in the upper block on the same page are the equations, with associated coefficients, that describe these curves.

In those instances where all RTGs, of a particular model were deployed and therefore unavailable for testing, physical characteristics, fueling information, previous electrical performance data, and a sketch of the model are provided on a single page.

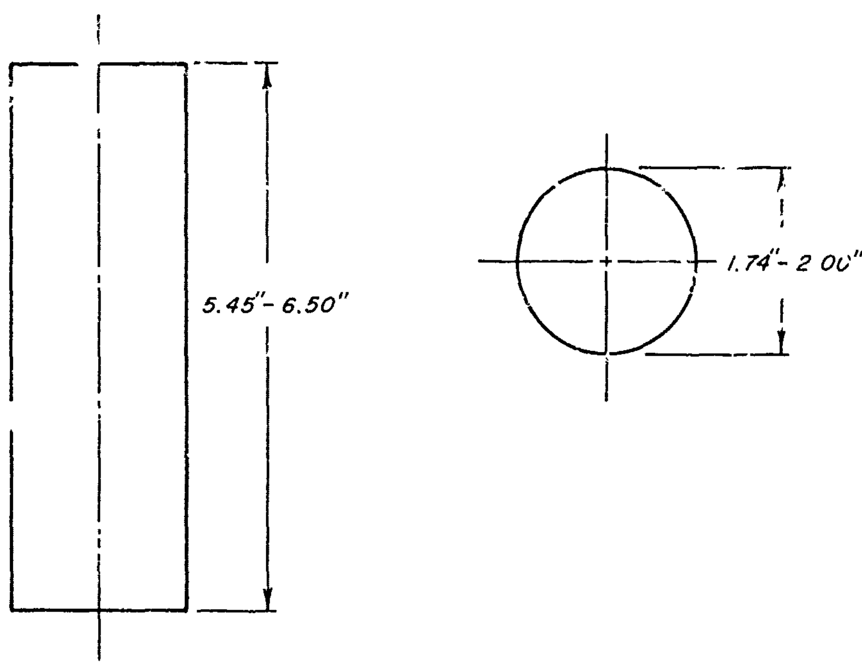
Numerical information is presented in exponential notation, i.e., 1.00 E 02 = 100 or 1.00 E – .02 = .01.

## HALF-WATT

APPLICABLE RTG NOS: SP0001, SP0002
GP0003, GP0004
TP0005, TP0006
NP0007, NP0008

PHYSICAL CHARACTERISTICS:

| | |
|---|---|
| WEIGHT (POUNDS) ............... | 3.00E 00 |
| PRESSURE HULL RATING (PSI) ... | TERRESTRIAL |
| PRESSURE HULL MATERIAL ....... | CU-BE |
| THERMOELECTRIC MATERIAL ...... | BITE |
| FUEL TYPE ........... ....... | PU-238 |



# RTG-TP0005 PERFORMANCE DATA

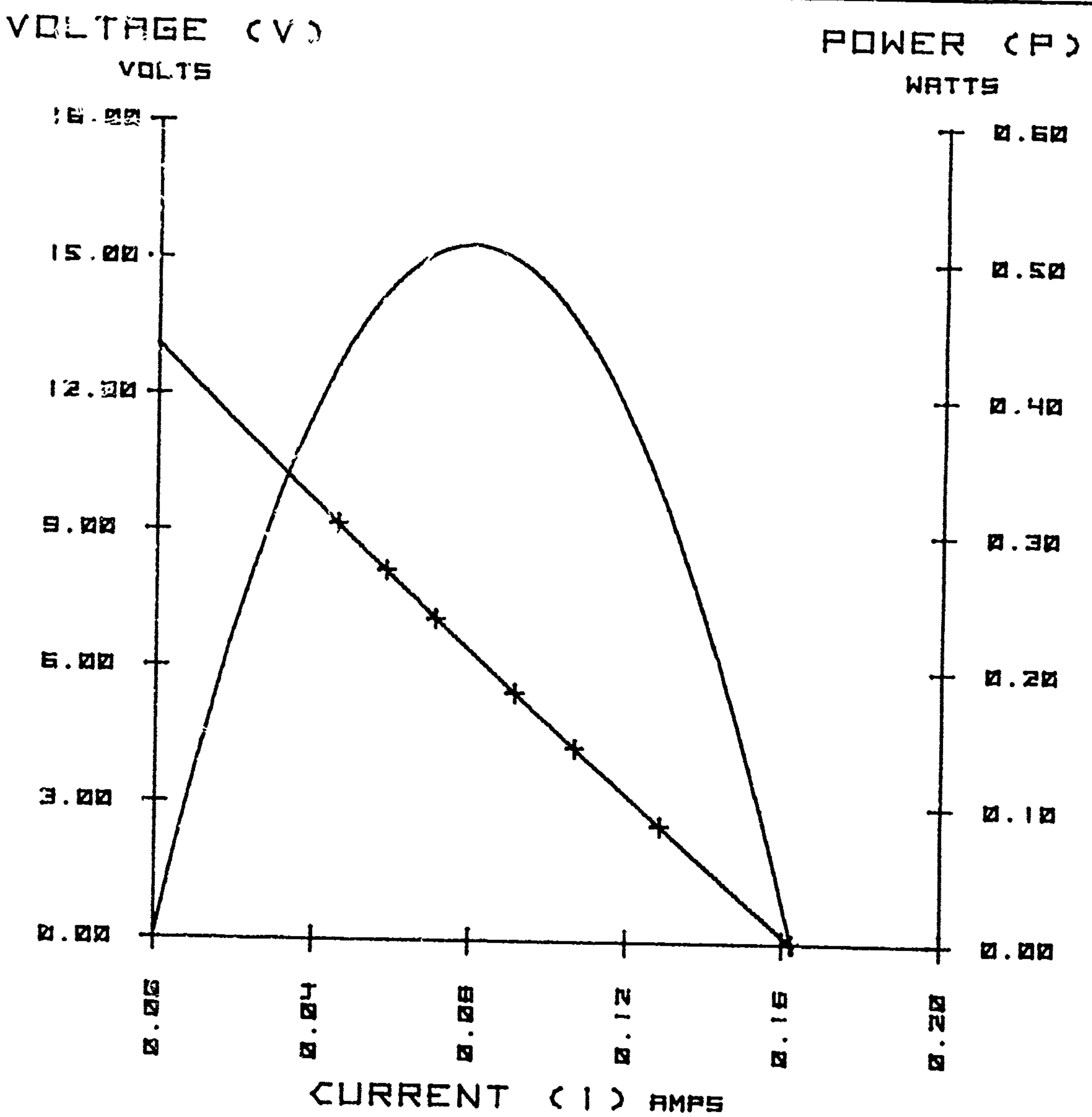
10 FEB 78

AMBIENT TEMP: 3.60 °C

| | | |
|---|---|---|
| V = A*I*I + B*I + C | A = | 4.03E 01 |
| | B = | -8.71E 01 |
| P = A*I*I*I + B*I*I + C*I | C = | 1.31E 01 |

MAX POWER.................. 5.11E-01 WATTS
VOLTAGE AT MAX POWER.... 6.42E 00 VOLTS
CURRENT AT MAX POWER.... 7.96E-02 AMPS
POWER CONDITIONING...... NONE

THERMAL OUTPUT (WATTS).. 1.72E 01 ]
FUEL ACTIVITY (CURIES).. 5.19E 02 ] DEC 74

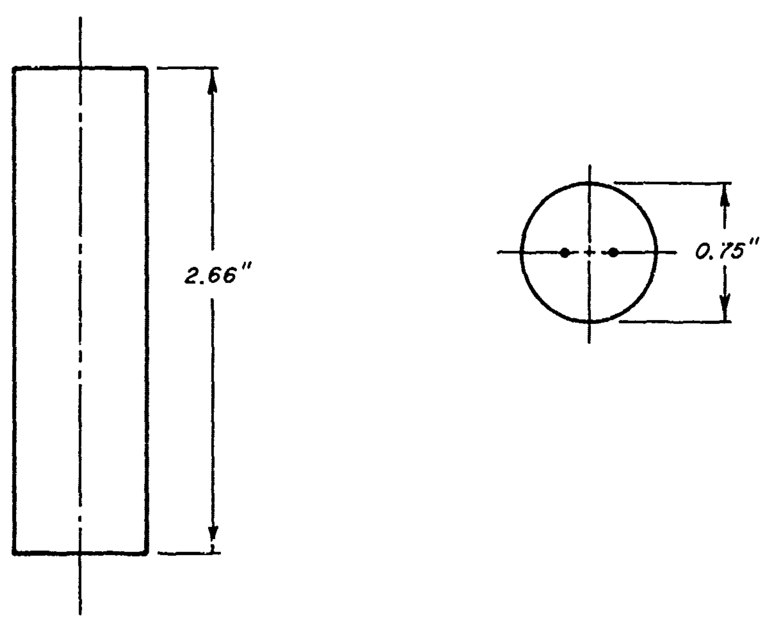


# IMPS

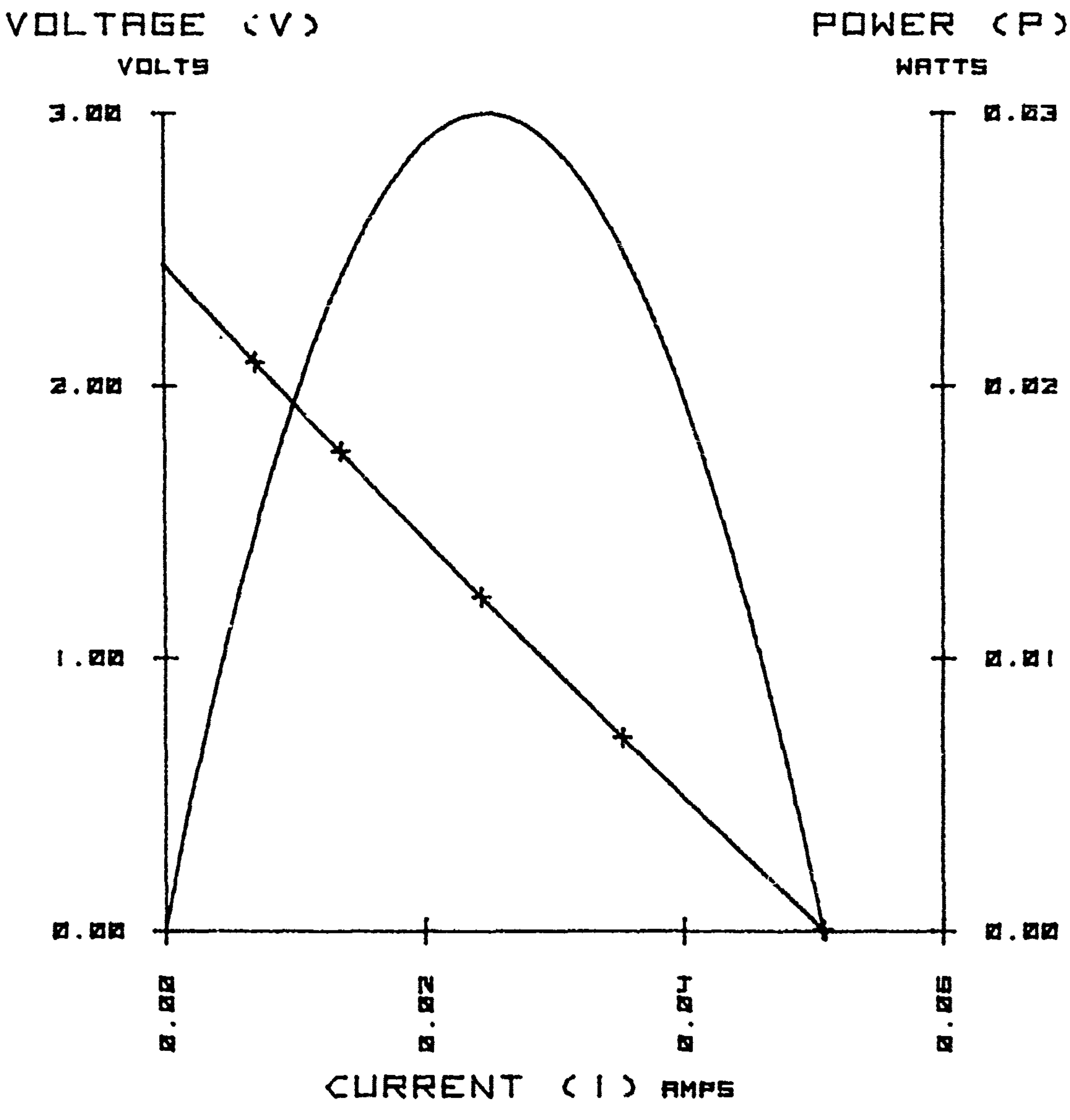
APPLICABLE RTG NOS: MRTGI

PHYSICAL CHARACTERISTICS:

| | |
|---|---|
| WEIGHT (POUNDS) .............. | 5.00E-01 |
| PRESSURE HULL RATING (PSI) ... | TERRESTRIAL |
| PRESSURE HULL MATERIAL ....... | TANTALUM |
| THERMOELECTRIC MATERIAL ...... | BITE |
| FUEL TYPE .................... | PU-238 |



| RTG-MRTG1 PERFORMANCE DATA | | |
|---|---|---|
| 25 JAN 78<br>AMBIENT TEMP: 21.5 °C | | |
| V = A*I*I + B*I + C<br>P = A*I*I*I + B*I*I + C*I | A = 6.98E 01<br>B = -5.16E 01<br>C = 2.45E 00 | |
| MAX POWER................. | 3.00E-02 | WATTS |
| VOLTAGE AT MAX POWER.... | 1.20E 00 | VOLTS |
| CURRENT AT MAX POWER.... | 2.50E-02 | AMPS |
| POWER CONDITIONING...... | NONE | |
| THERMAL OUTPUT (WATTS).. | 1.13E 00 | FEB 71 |
| FUEL ACTIVITY (CURIES).. | 3.55E 01 | |

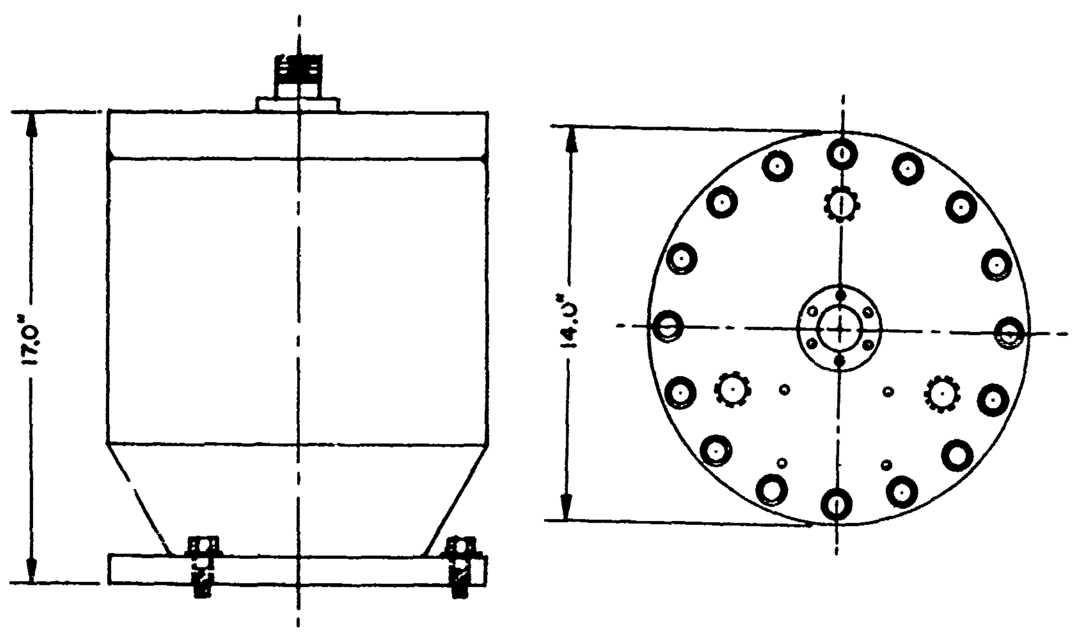


# MILLIBATT-1000

APPLICABLE RTG NOS: 033-040

PHYSICAL CHARACTERISTICS:

| | |
|---|---|
| WEIGHT (POUNDS) ................ | 7.50E 02 |
| PRESSURE HULL RATING (PSI) ... | 1.00E 04 |
| PRESSURE HULL MATERIAL ....... | STEEL |
| THERMOELECTRIC MATERIAL ...... | BITE |
| FUEL TYPE ..................... | SR-90 |



## RTG-039 PERFORMANCE DATA

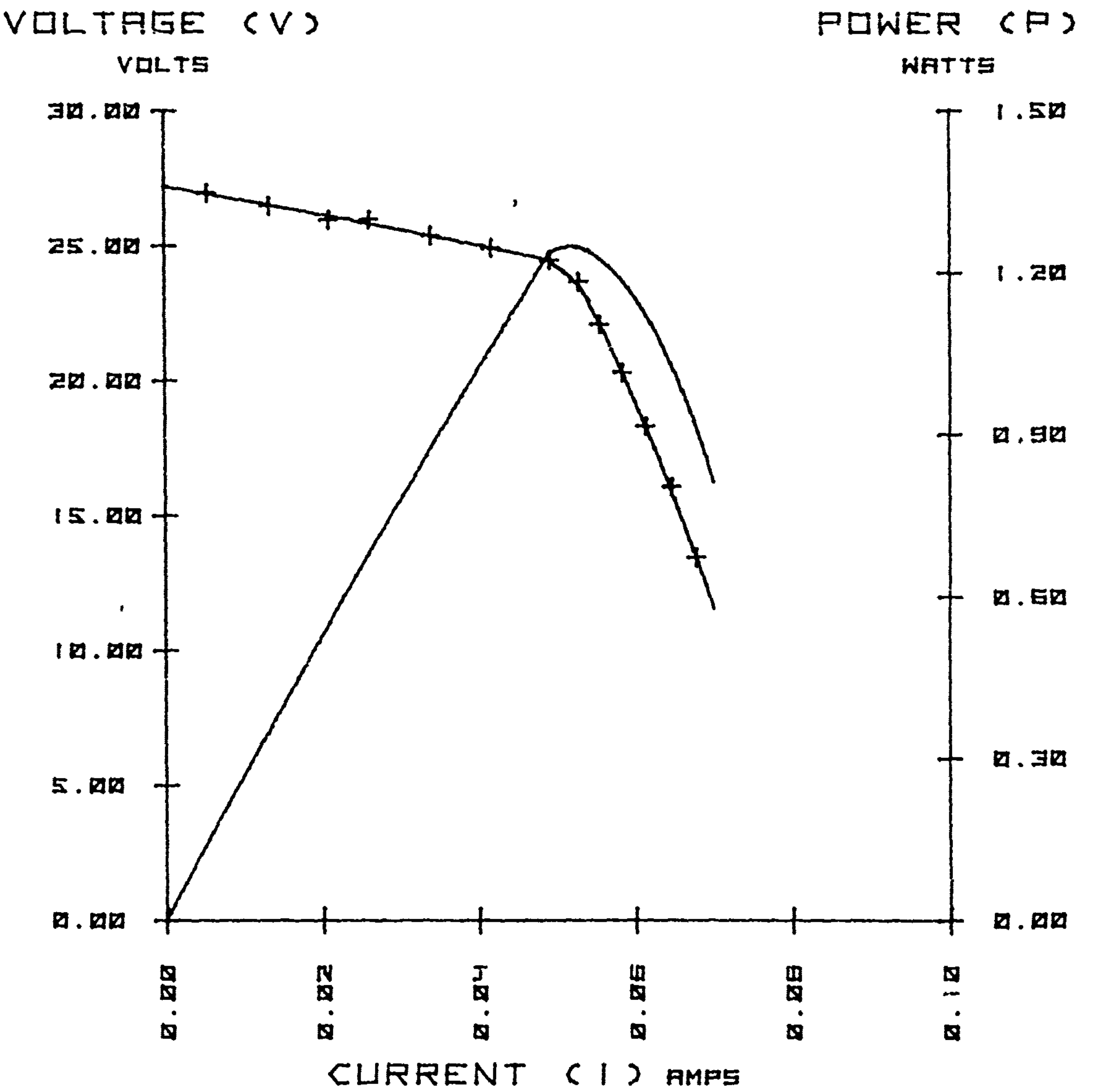
10 JAN 78
AMBIENT TEMP: 20.5 °C

$V = A*I*I + B*I + C$

$P = A*I*I*I + B*I*I + C*I$

A = N/A
B = N/A
C = N/A

| | |
|---|---|
| MAX POWER............... | 1.27E 00 WATTS |
| VOLTAGE AT MAX POWER.... | 2.47E 01 VOLTS |
| CURRENT AT MAX POWER.... | 5.15E-02 AMPS |
| POWER CONDITIONING...... | 24 VDC REGULATED |
| THERMAL OUTPUT (WATTS).. | 5.30E 01 (FEB 72) |
| FUEL ACTIVITY (CURIES).. | 7.75E 03 (FEB 72) |



# SENTINEL-8

APPLICABLE RTG NOS: 024

PHYSICAL CHARACTERISTICS:

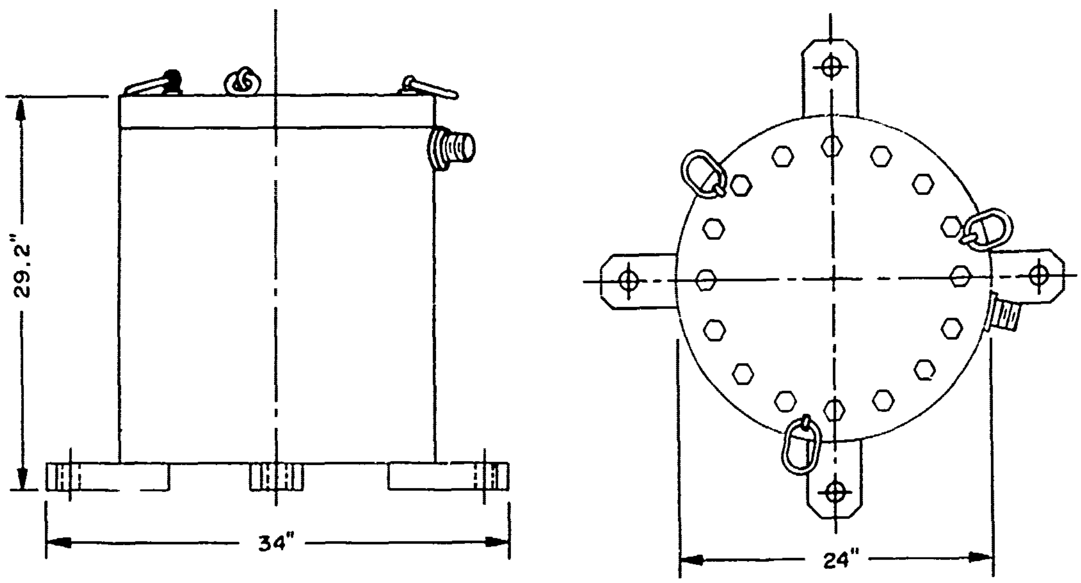
| | |
|---|---|
| WEIGHT (POUNDS) .. ........... | 3.15E 03 |
| PRESSURE HULL RATI G (PSI) ... | 1.67E 03 |
| PRESSURE HULL MATERIAL ....... | STEEL |
| THERMOELECTRIC MATERIAL ...... | PBTE |

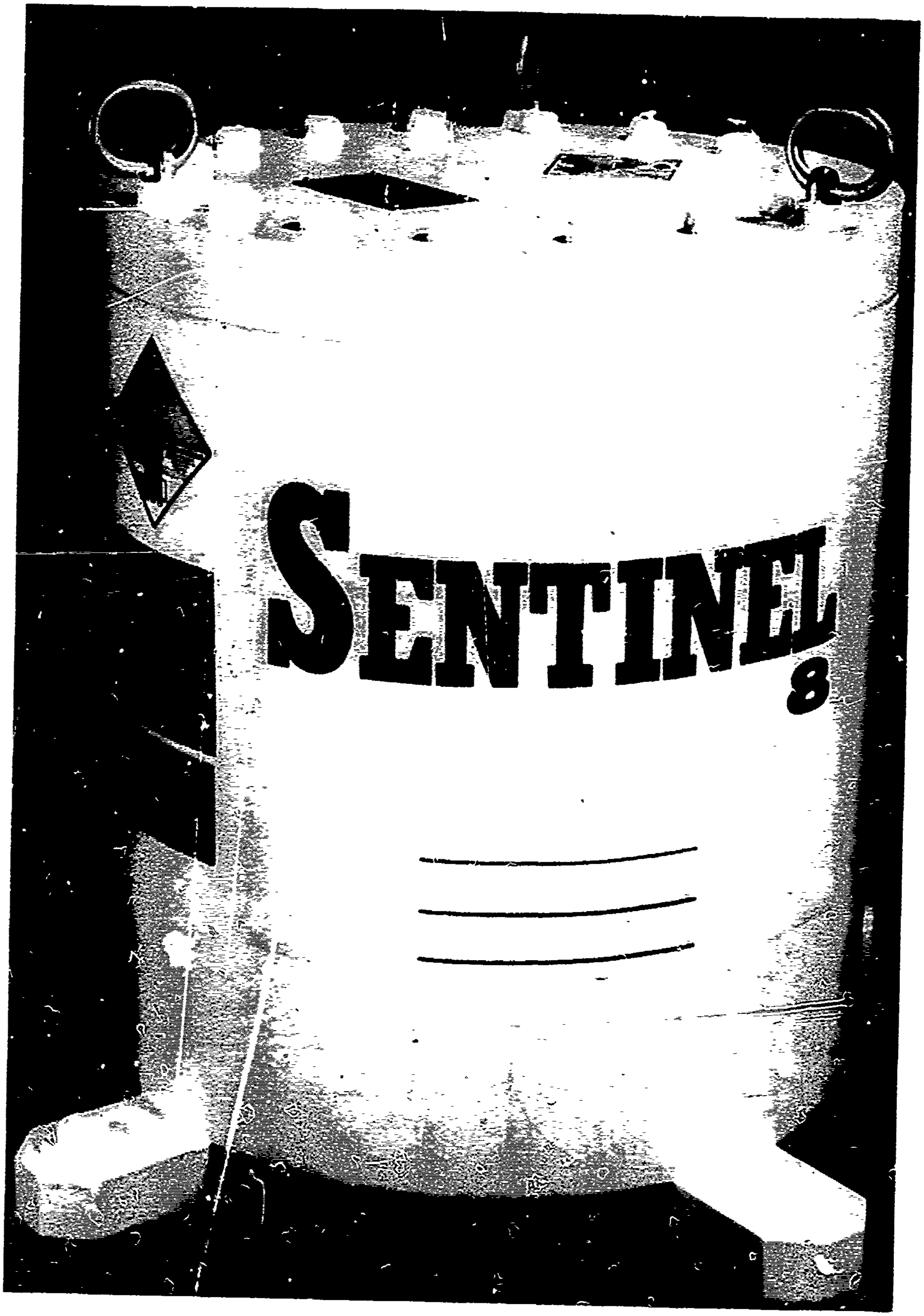
FUELING INFORMATION:

| | |
|---|---|
| FUEL TYPE .................... | SR-90 |
| FUELING DATE ................. | DEC 68 |
| FUELED THERMAL WATTS ......... | 2.55E 02 |
| FUELED CURIES ................ | 3.75E 04 |

ELECTRICAL CHARACTERISTICS: AS OF DEC 77

| | |
|---|---|
| MAXIMUM POWER ................ | 7.93E 00 |
| VOLTAGE AT MAXIMUM POWER ..... | 1.48E 00 |
| CURRENT AT MAXIMUM POWER ..... | 5.35E 00 |




SENTINEL
8

# SENTINEL-25A

APPLICABLE RTG NOS: 001

PHYSICAL CHARACTERISTICS:

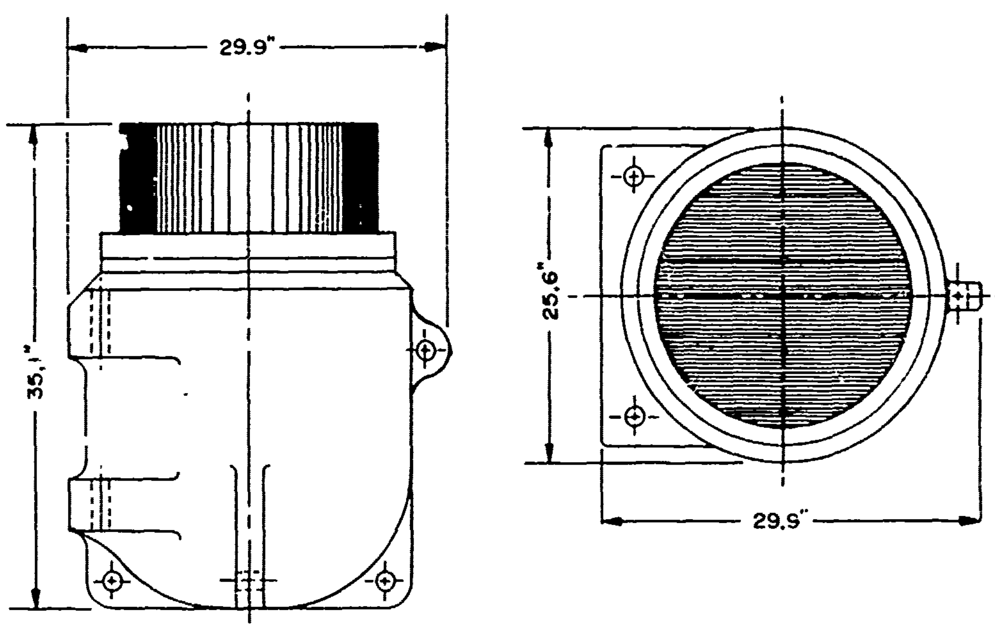
| | |
|---|---|
| WEIGHT (POUNDS) ............... | 3.00E 03 |
| PRESSURE HULL RATING (PSI) ... | TERRESTRIAL |
| PRESSURE HULL MATERIAL ....... | STEEL |
| THERMOELECTRIC MATERIAL ...... | PBTE |

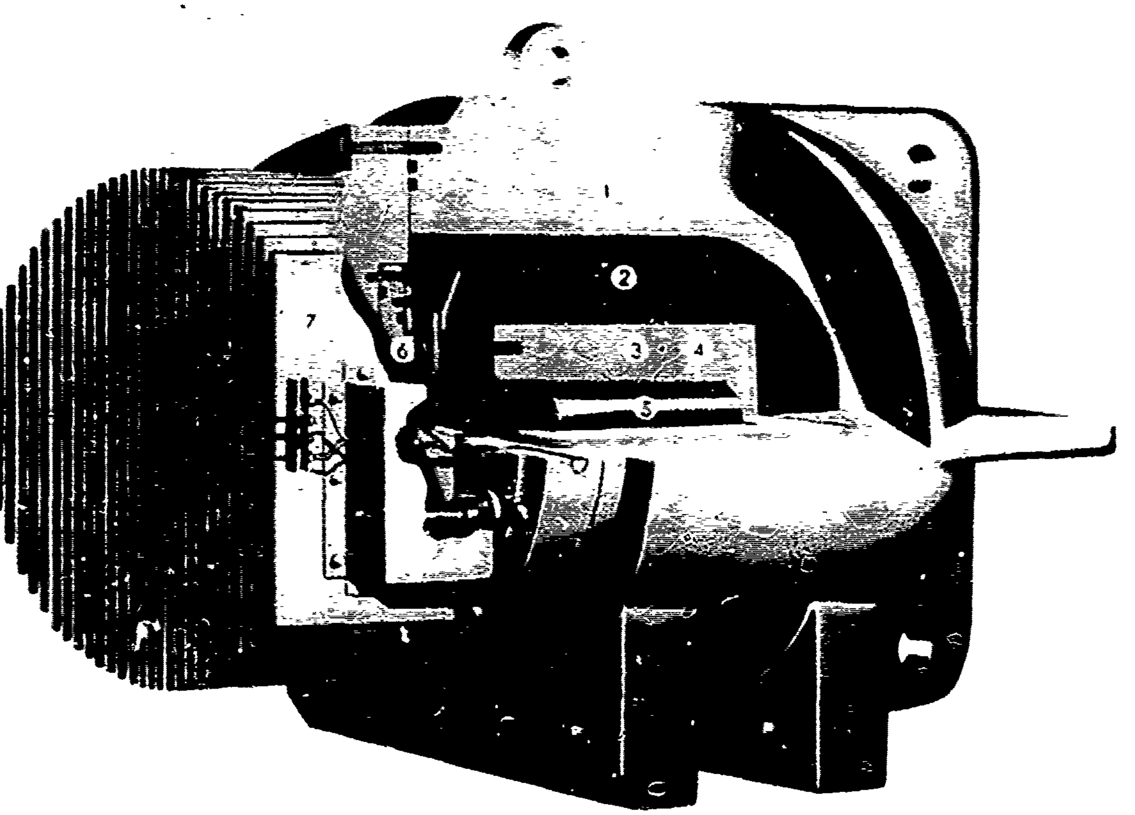
FUELING INFORMATION:

| | |
|---|---|
| FUEL TYPE .................... | SR-90 |
| FUELING DATE ................. | JUN 66 |
| FUELED THERMAL WATTS .. ...... | 7.15E 02 |
| FUELED CURIES ................ | 1.25E 05 |

ELECTRICAL CHARACTERISTICS: AS OF JUN 75

| | |
|---|---|
| MAXIMUM POWER ................ | 1.18E 01 |
| VOLTAGE AT MAXIMUM POWER ..... | 2.48E 00 |
| CURRENT AT MAXIMUM POWER ..... | 4.76E 00 |



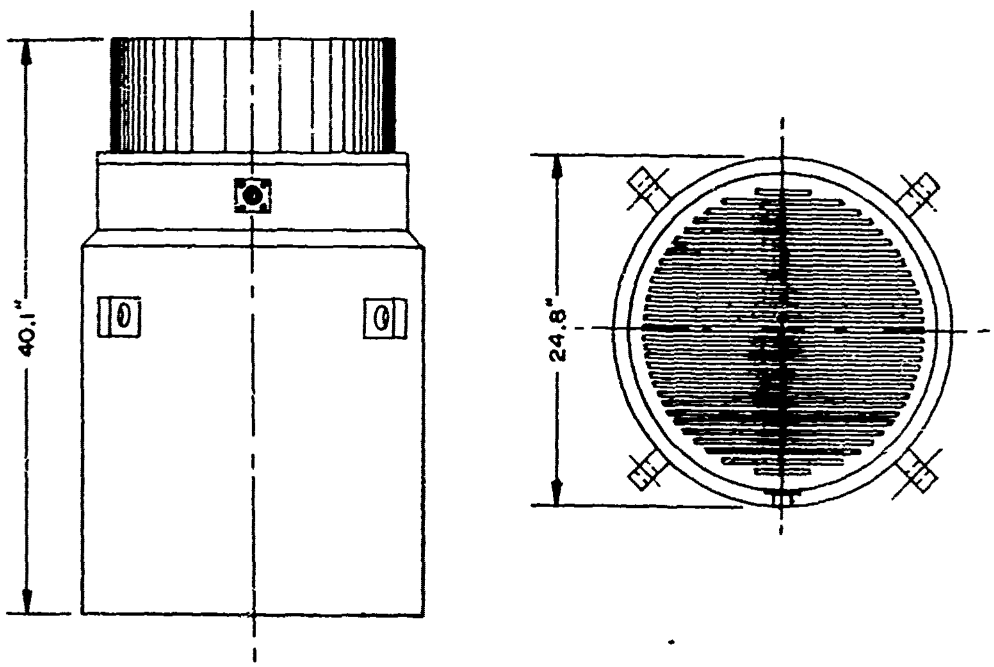

1 SHIELD
2 INSULATION
3 INNER SHIELD
4 FUEL CAPSULE
5 RADIOISOTOPIC FUEL
6 THERMOELECTRIC COUPLE ASSEMBLY
7 RADIATOR FINS (ALUMINUM PLATE)
2
3 4
5
6
7

# SENTINEL-25C1

APPLICABLE RTG NOS: 006

PHYSICAL CHARACTERISTICS:

| | |
|---|---|
| WEIGHT (POUNDS) ............... | 2.00E 03 |
| PRESSURE HULL RATING (PSI) ... | 6.00E 03 |
| PRESSURE HULL MATERIAL ....... | ALUMINUM |
| THERMOELECTRIC MATERIAL ...... | PBTE |
| FUEL TYPE .................... | SR-90 |



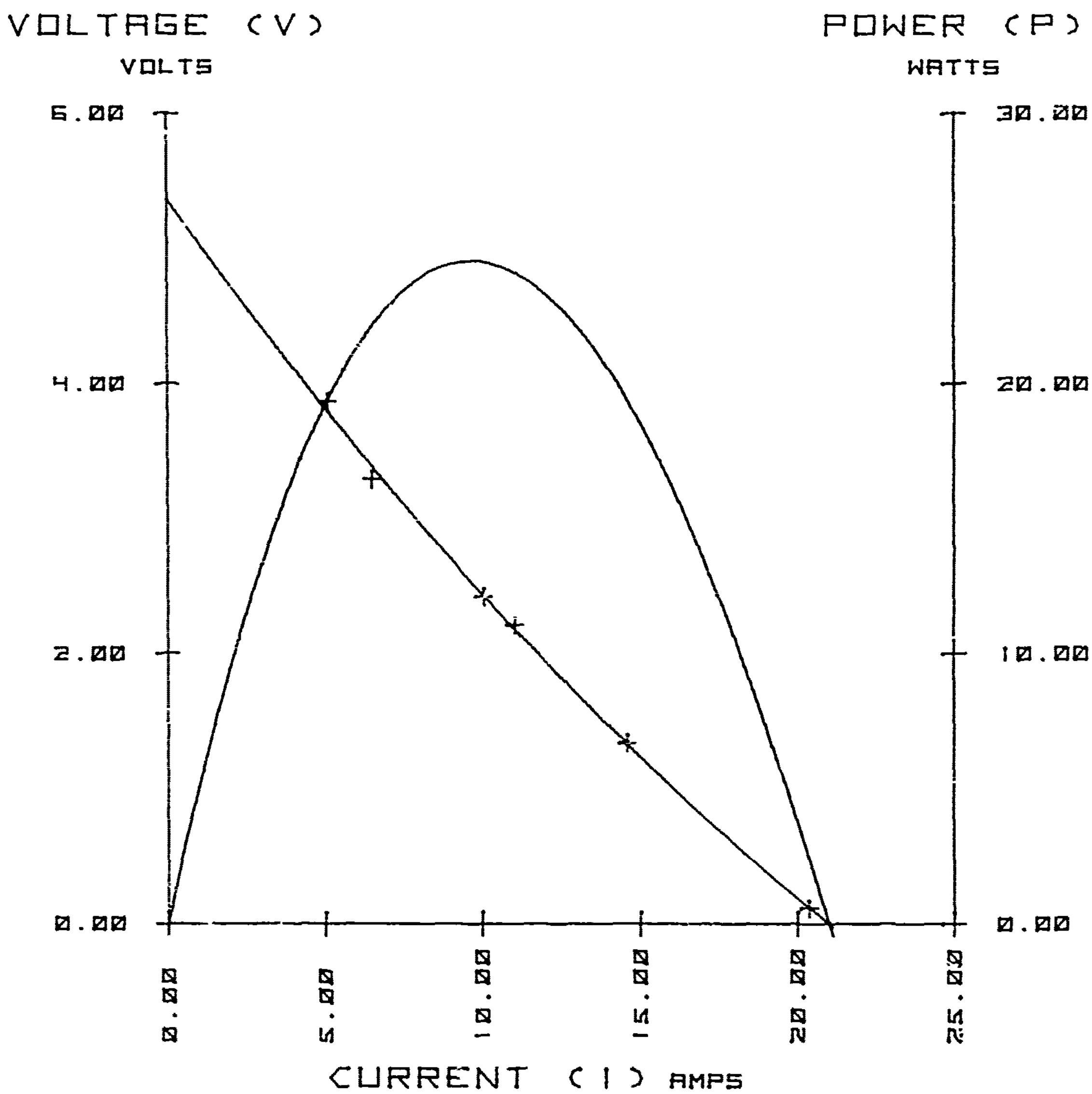
# RTG-006 PERFORMANCE DATA

10 JAN 78
AMBIENT TEMP: 21.4 °C

| | |
|---|---|
| V = A*I*I + B*I + C | A = 3.29E-03 |
| | B = -3.24E-01 |
| P = A*I*I*I + B*I*I + C*I | C = 5.37E 00 |

MAX POWER............... 2.45E 01 WATTS
VOLTAGE AT MAX POWER.... 2.53E 00 VOLTS
CURRENT AT MAX POWER.... 9.70E 00 AMPS
POWER CONDITIONING...... NONE

THERMAL OUTPUT (WATTS).. 7.43E 02 ] SEP 67
FUEL ACTIVITY (CURIES).. 1.09E 05 ]

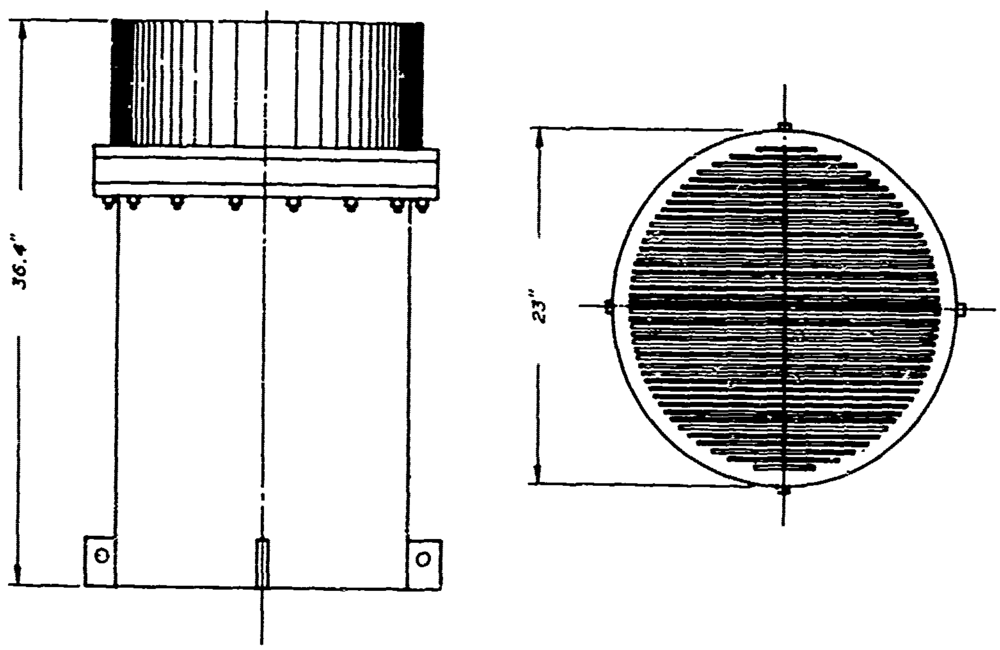


# SENTINEL-25C3

APPLICABLE RTG NOS: 014

PHYSICAL CHARACTERISTICS:

| | |
|---|---|
| WEIGHT (POUNDS) ............... | 1.28E 03 |
| PRESSURE HULL RATING (PSI) ... | 5.00E 02 |
| PRESSURE HULL MATERIAL ........ | ALUMINUM |
| THERMOELECTRIC MATERIAL ...... | PBTE |
| FUEL TYPE ....................... | SR-90 |



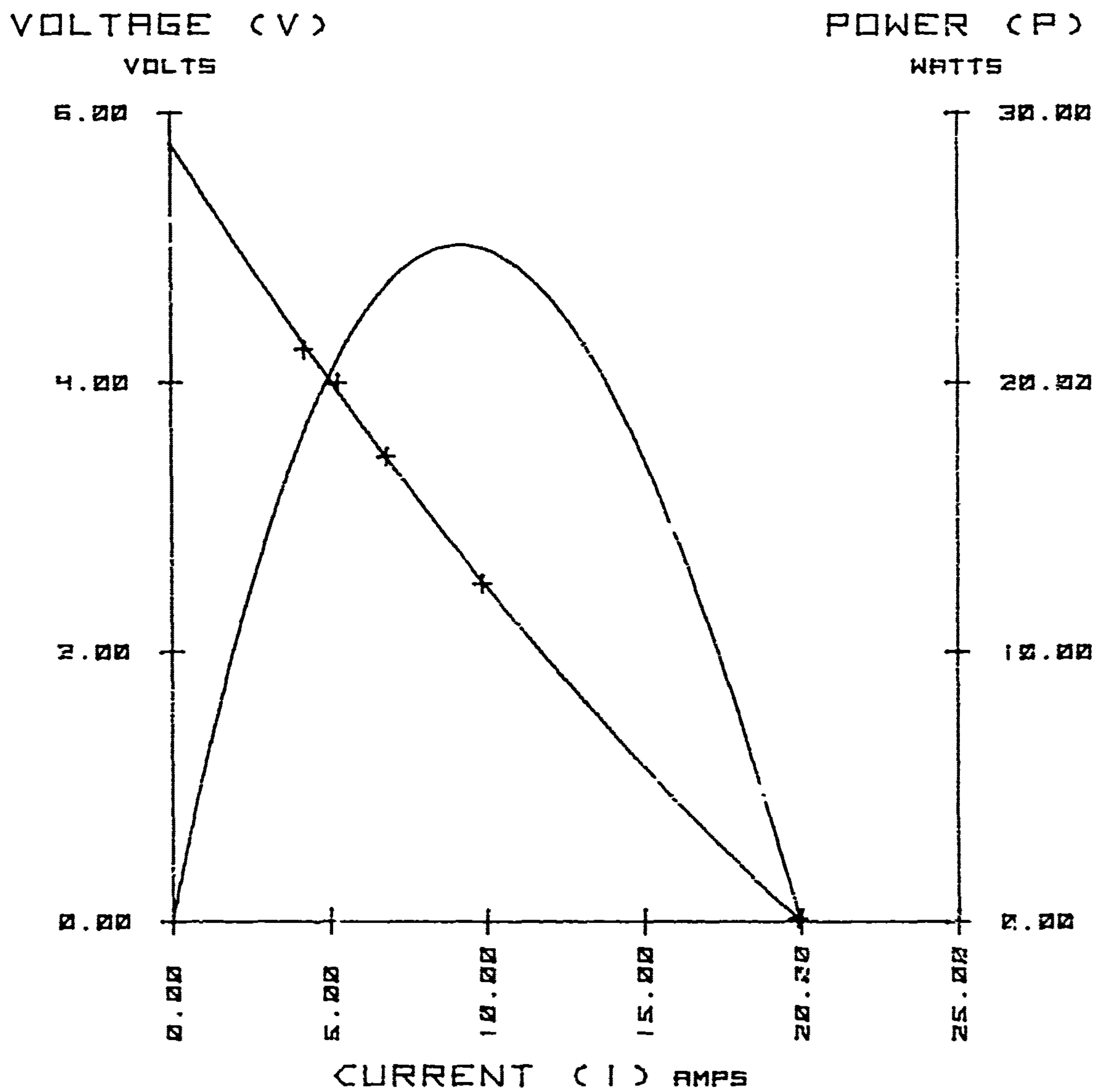
# RTG-014 PERFORMANCE DATA

23 DEC 77
AMBIENT TEMP: 21.7 °C

| | |
|---|---|
| V = A*I*I + B*I + C<br>P = A*I*I*I + B*I*I + C*I | A = 3.89E-03<br>B = -3.67E-01<br>C = 5.77E 00 |

MAX POWER.............. 2.51E 01 WATTS
VOLTAGE AT MAX POWER.... 2.72E 00 VOLTS
CURRENT AT MAX POWER.... 9.23E 00 AMPS
POWER CONDITIONING...... NONE

THERMAL OUTPUT (WATTS).. 7.20E 02 ] DEC 69
FUEL ACTIVITY (CURIES).. 1.06E 05 ]



# SENTINEL-25D

APPLICABLE RTG NOS: 008-010

PHYSICAL CHARACTERISTICS:

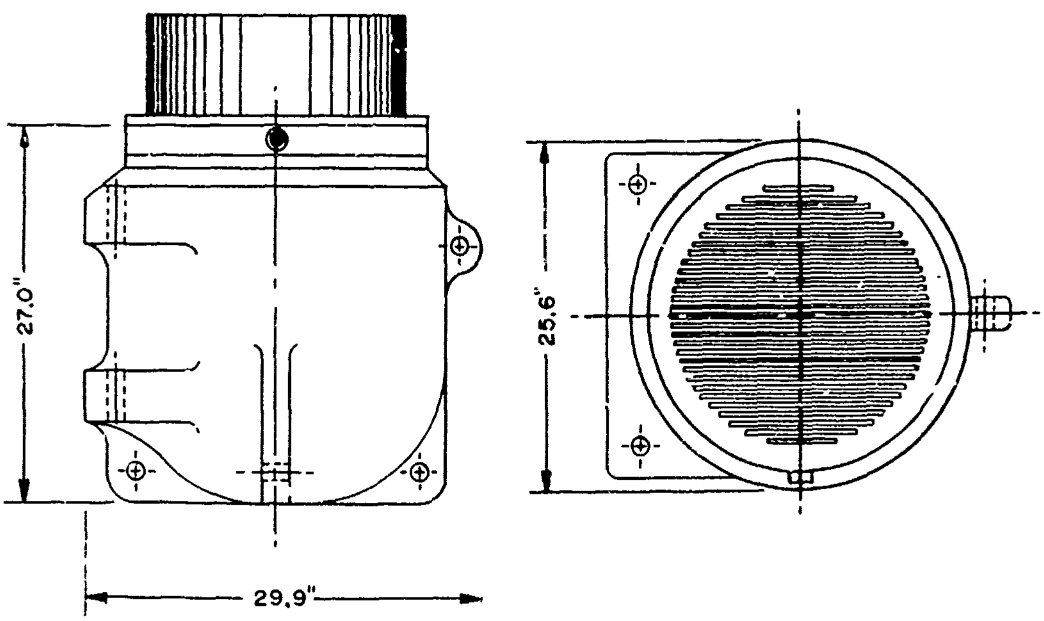
- WEIGHT (POUNDS) . . . . . . . . . . . . . . . . 3.00E 03
- PRESSURE HULL RATING (PSI) . . . 1.00E 03
- PRESSURE HULL MATERIAL . . . . . . . STEEL
- THERMOELECTRIC MATERIAL . . . . . . PBTE

FUELING INFORMATION:

- FUEL TYPE . . . . . . . . . . . . . . . . . . . . . . SR-90
- FUELING DATE . . . . . . . . . . . . . . . . . . OCT 69
- FUELED THERMAL WATTS . . . . . . . . . 7.21E 02
- FUELED CURIES . . . . . . . . . . . . . . . . 1.06E 05

ELECTRICAL CHARACTERISTICS: AS OF JAN 73

- MAXIMUM POWER . . . . . . . . . . . . . . . . 3.56E 01
- VOLTAGE AT MAXIMUM POWER . . . . . 2.90E 01
- CURRENT AT MAXIMUM POWER . . . . . 1.23E 0



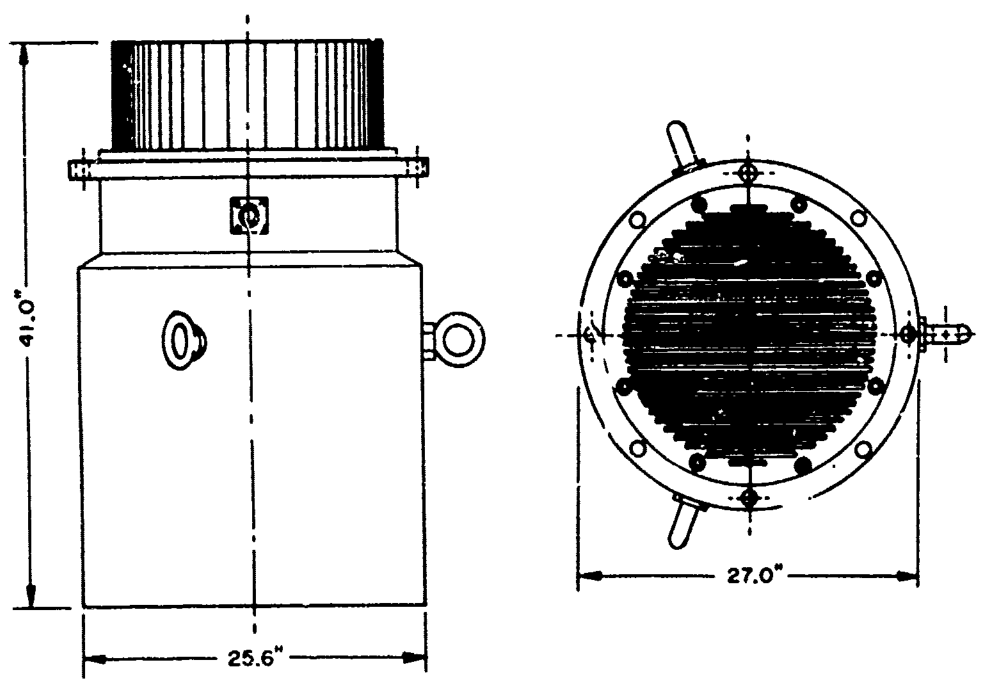

U.S.NAVY
RTG-10
U.S.NAVY
RTG-9

# SENTINEL-25E

APPLICABLE RTG NOS: 011-013

PHYSICAL CHARACTERISTICS:

| | |
|---|---|
| WEIGHT (POUNDS) | 4.17E 03 |
| PRESSURE HULL RATING (PSI) | 1.00E 04 |
| PRESSURE HULL MATERIAL | STEEL |
| THERMOELECTRIC MATERIAL | PBTE |
| FUEL TYPE | SR-90 |



## RTG-012 PERFORMANCE DATA

12 DEC 77

AMBIENT TEMP: 20.0 °C

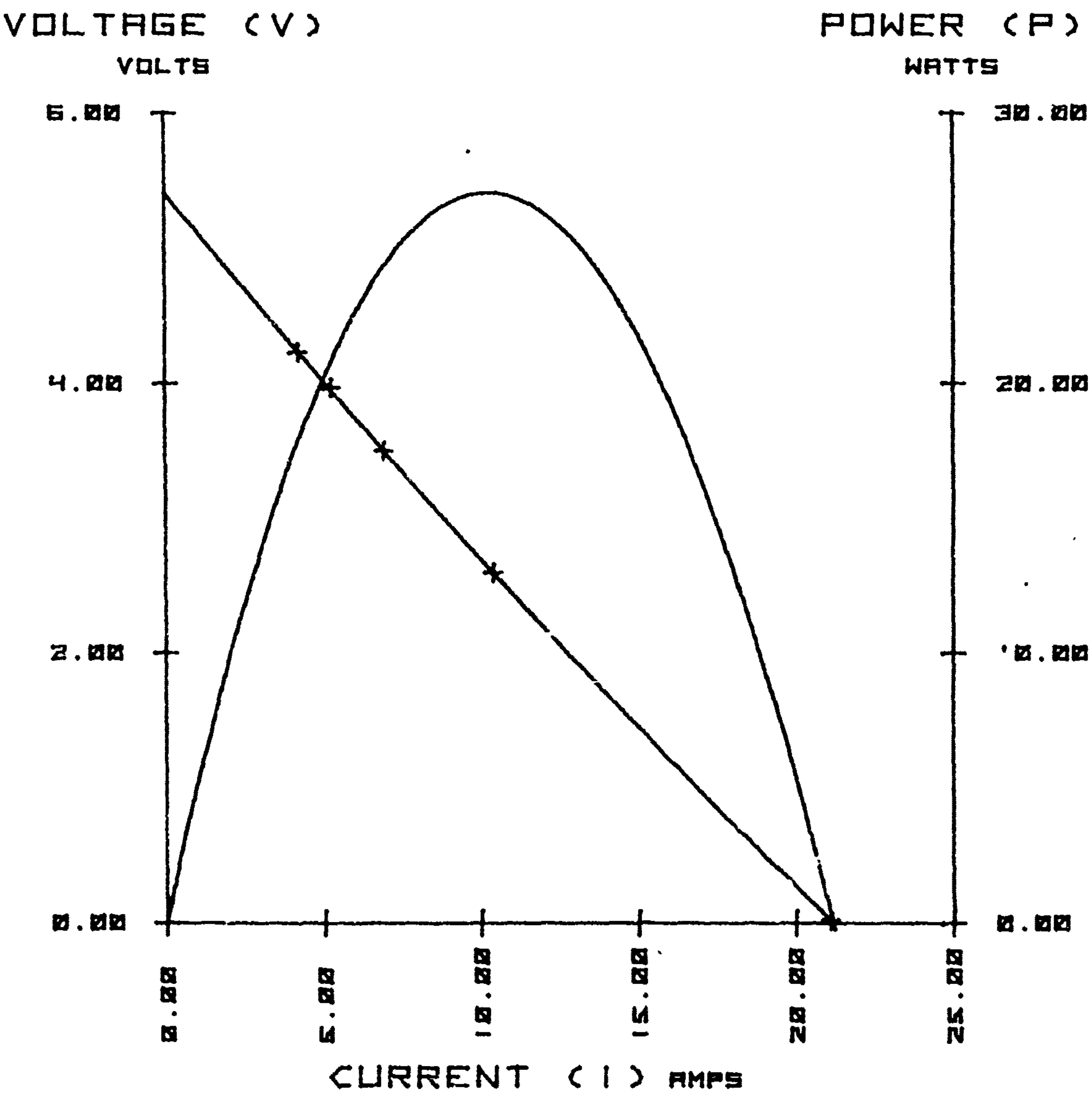
V = A*I*I + B*I + C

P = A*I*I*I + B*I*I + C*I

A = 1.38E-03
B = -2.84E-01
C = 5.41E 00

MAX POWER............... 2.71E 01 WATTS
VOLTAGE AT MAX POWER.... 2.63E 00 VOLTS
CURRENT AT MAX POWER.... 1.03E 01 AMPS
POWER CONDITIONING...... NONE

THERMAL OUTPUT (WATTS).. 7.19E 02
FUEL ACTIVITY (CURIES).. 1.08E 05
DEC 68

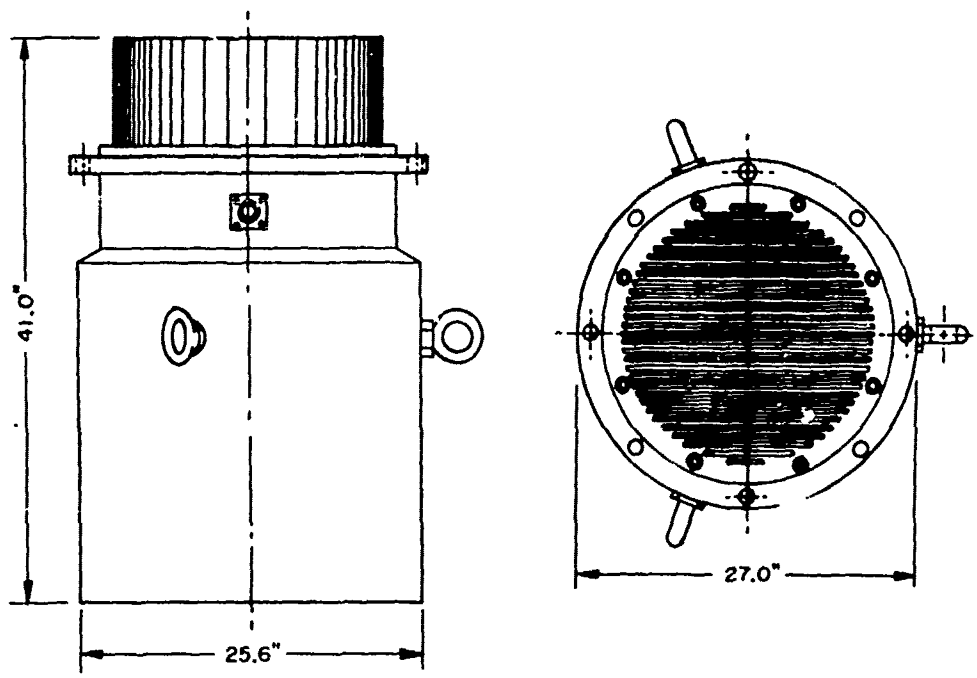


# SENTINEL-25E

APPLICABLE RTG NOS: 029-032

PHYSICAL CHARACTERISTICS:

| | |
|---|---|
| WEIGHT (POUNDS) ............... | 4.17E 03 |
| PRESSURE HULL RATING (PSI) ... | 1.00E 04 |
| PRESSURE HULL MATERIAL ....... | STEEL |
| THERMOELECTRIC MATERIAL ...... | PBTE |
| FUEL TYPE .................... | SR-90 |



# RTG-031 PERFORMANCE DATA

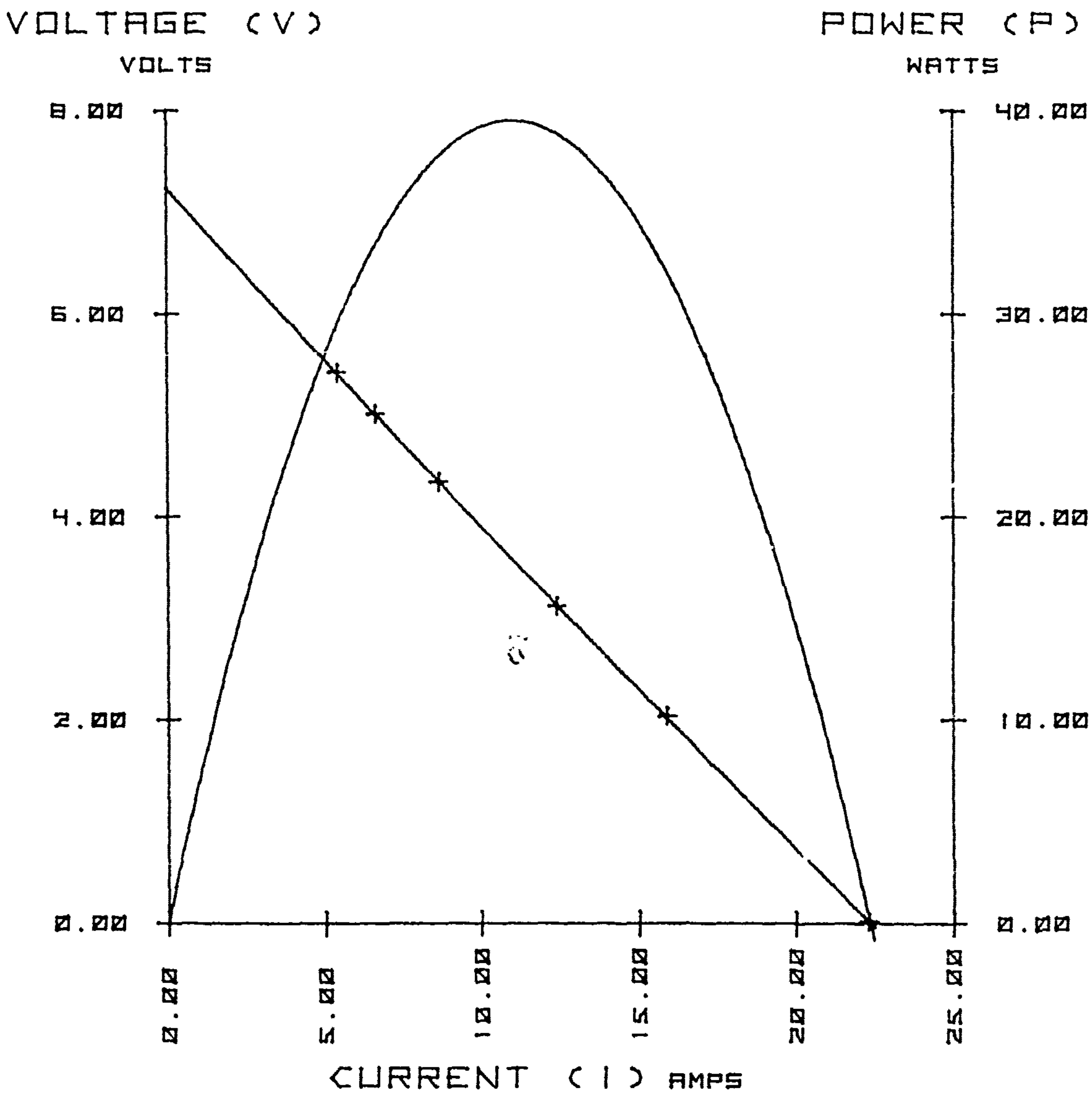
19 DEC 77
AMBIENT TEMP: 21.0 °C

V = A*I*I + B*I + C
P = A*I*I*I + B*I*I + C*I

A = 7.32E-04
B = -3.40E-01
C = 7.24E 00

MAX POWER............... 3.95E 01 WATTS
VOLTAGE AT MAX POWER.... 3.58E 00 VOLTS
CURRENT AT MAX POWER.... 1.10E 01 AMPS
POWER CONDITIONING...... NONE

THERMAL OUTPUT (WATTS).. 7.19E 02 ⎤
FUEL ACTIVITY (CURIES).. 1.06E 05 ⎦ APR 71

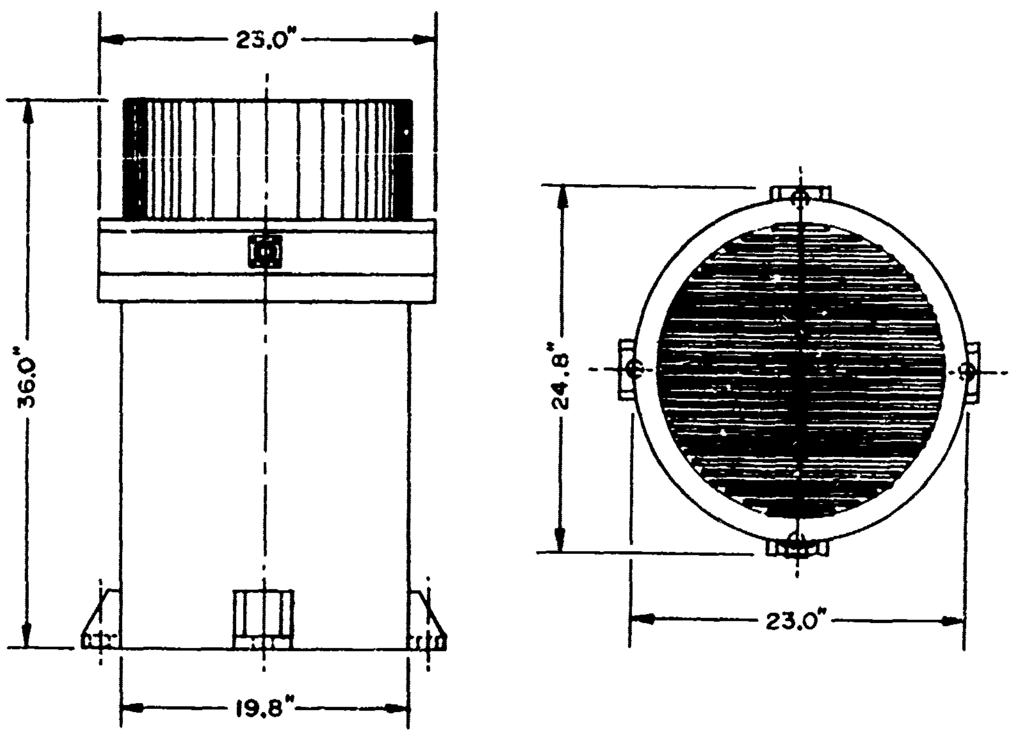


# SENTINEL-25F

APPLICABLE RTG NOS: 019-023

PHYSICAL CHARACTERISTICS:

| | |
|---|---|
| WEIGHT (POUNDS) ............... | 1.40E 03 |
| PRESSURE HULL RATING (PSI) ... | 5.00E 02 |
| PRESSURE HULL MATERIAL ....... | ALUMINUM |
| THERMOELECTRIC MATERIAL ...... | PBTE |
| FUEL TYPE .................... | SR-90 |



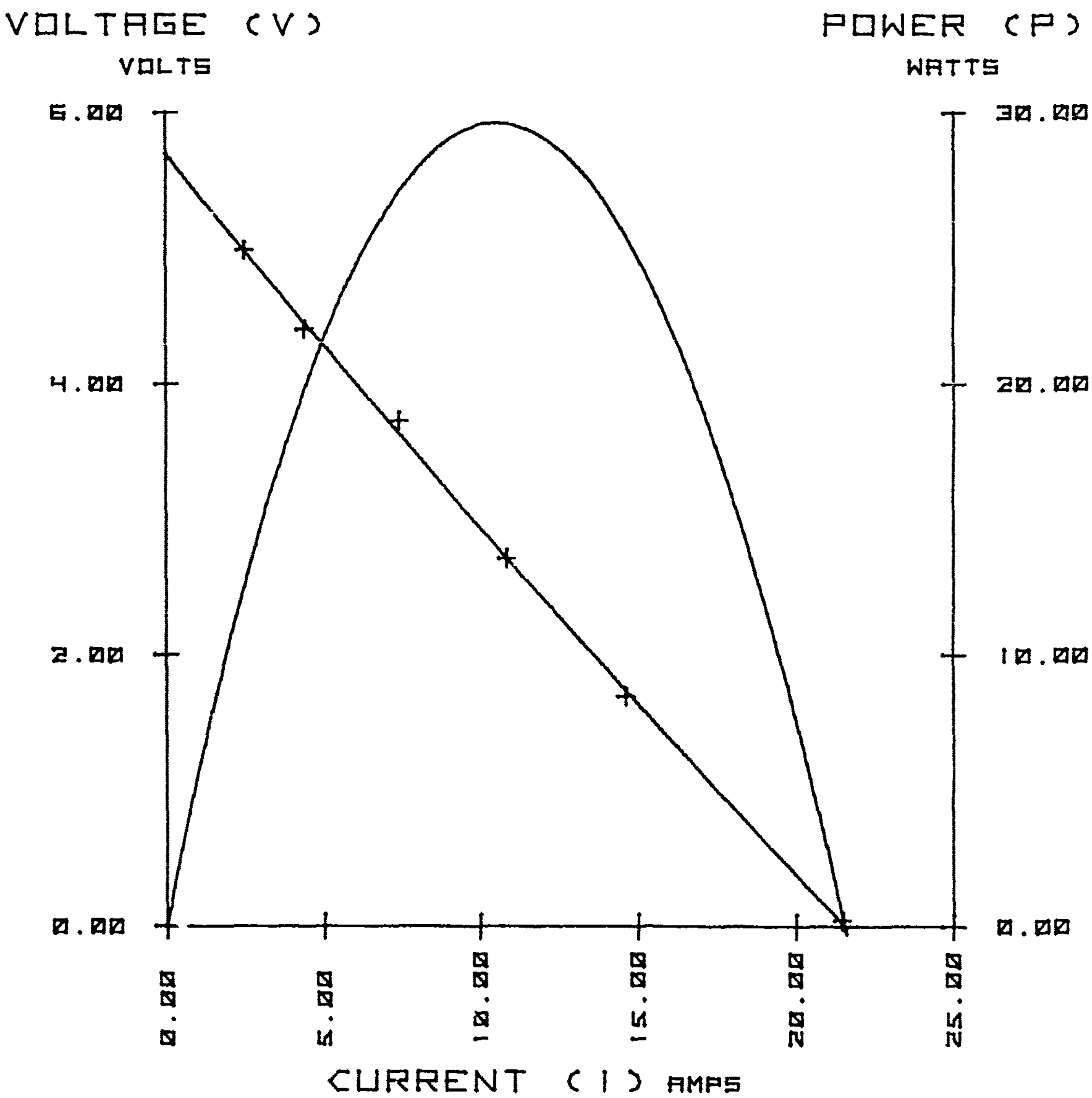
# RTG-023 PERFORMANCE DATA

26 MAY 77
AMBIENT TEMP: 20.5 °C

| | | |
|---|---|---|
| V = A*I*I + B*I + C | A = | 8.90E-04 |
| | B = | -2.93E-01 |
| P = A*I*I*I + B*I*I + C*I | C = | 5.69E 00 |

MAX POWER.............. 2.36E 01 WATTS
VOLTAGE AT MAX POWER.... 2.80E 00 VOLTS
CURRENT AT MAX POWER.... 1.06E 01 AMPS
POWER CONDITIONING...... NONE

THERMAL OUTPUT (WATTS).. 7.35E 02 ] DEC 70
FUEL ACTIVITY (CURIES).. 1.08E 05



# SENTINEL-100F

APPLICABLE RTG NOS: 041

PHYSICAL CHARACTERISTICS:

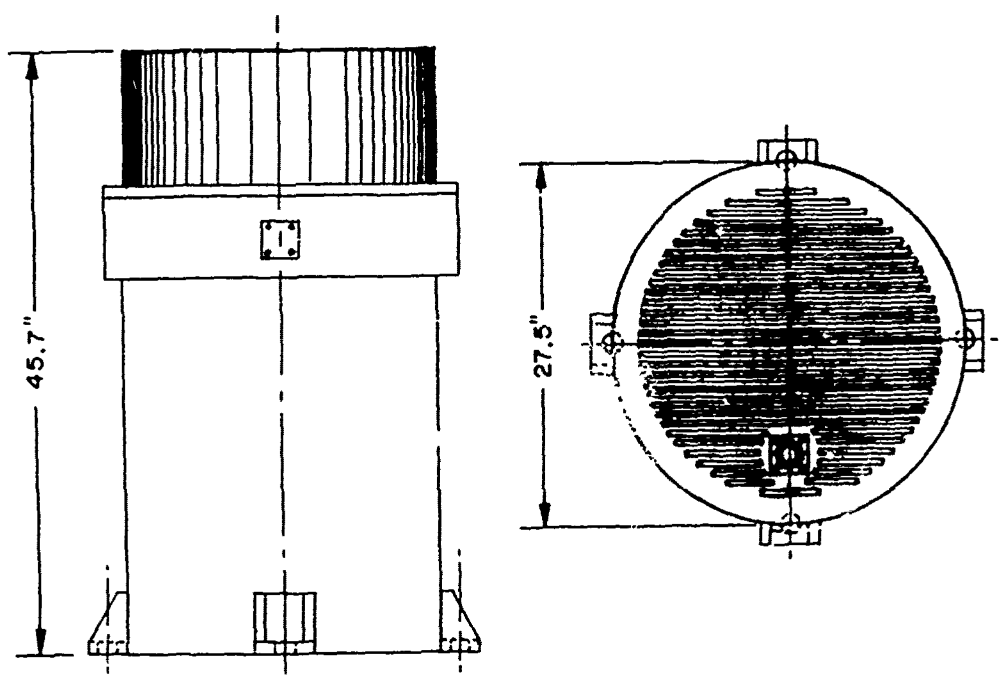
| | |
|---|---|
| WEIGHT (POUNDS) . . . . . . . . . . . . . . . | 2.72E 03 |
| PRESSURE HULL RATING (PSI) . . . | 5.00E 02 |
| PRESSURE HULL MATERIAL . . . . . . . | ALUMINUM |
| THERMOELECTRIC MATERIAL . . . . . . | PBTE |

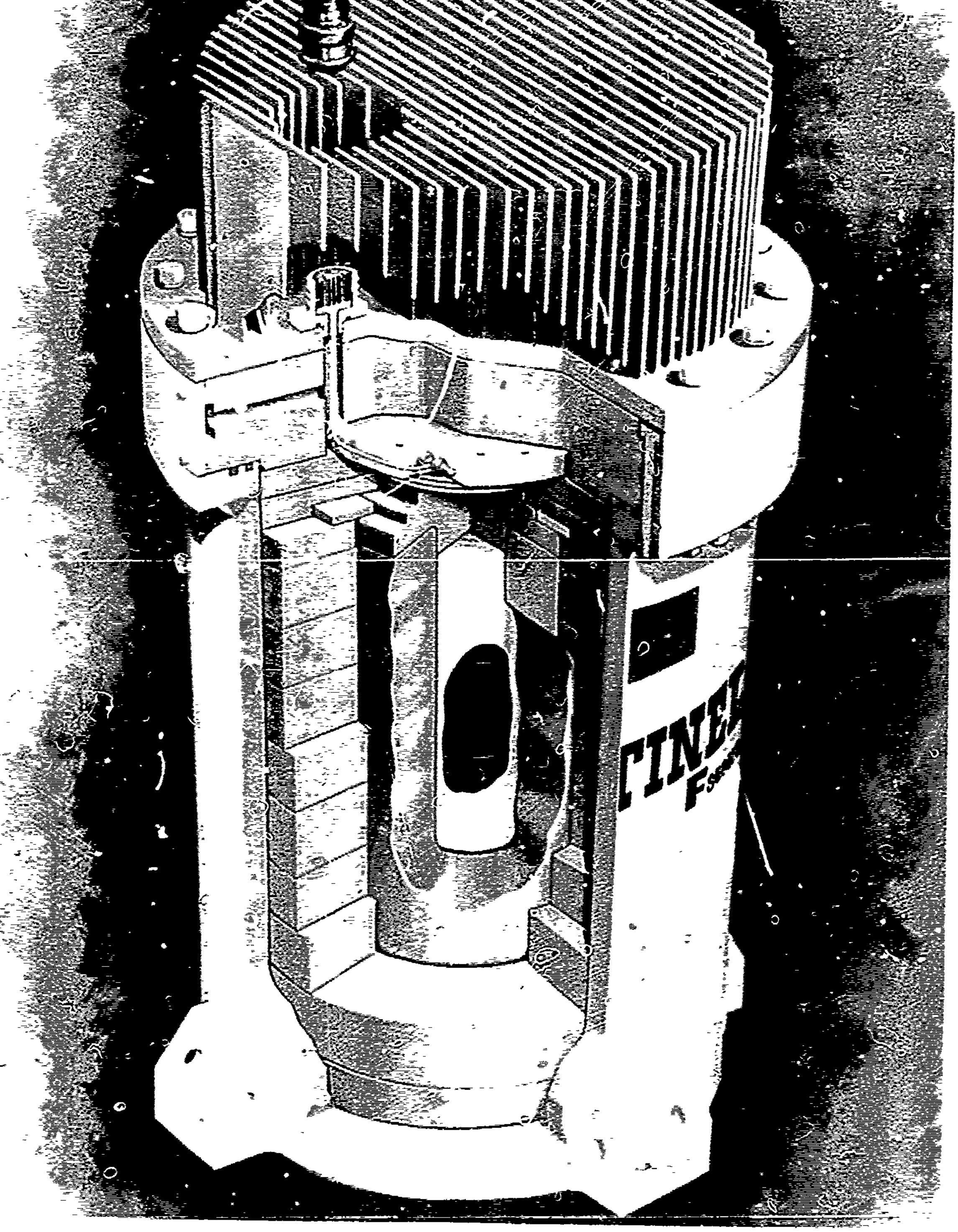
FUELING INFORMATION:

| | |
|---|---|
| FUEL TYPE . . . . . . . . . . . . . . . . . . . . . | SR-90 |
| FUELING DATE . . . . . . . . . . . . . . . . . | MAY 72 |
| FUELED THERMAL WATTS . . . . . . . . . | 2.23E 03 |
| FUELED CURIES . . . . . . . . . . . . . . . . | 3.28E 05 |

ELECTRICAL CHARACTERISTICS: AS OF OCT 73

| | |
|---|---|
| MAXIMUM POWER . . . . . . . . . . . . . . . | 1.40E 02 |
| VOLTAGE AT MAXIMUM POWER . . . . . | 9.15E 00 |
| CURRENT AT MAXIMUM POWER . . . . . | 1.53E 01 |





# SNAP-7E

APPLICABLE RTG NOS: S7E

PHYSICAL CHARACTERISTICS:

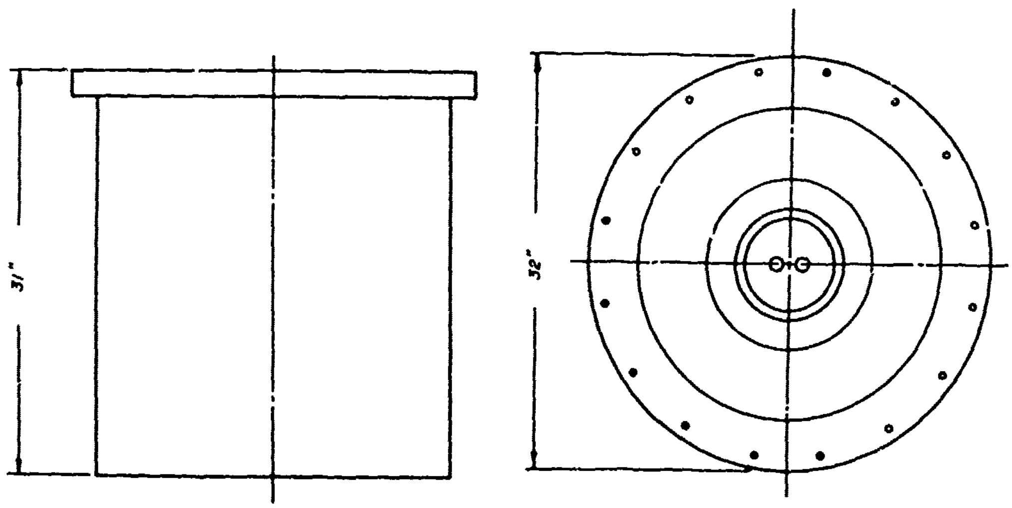
| | |
|---|---|
| WEIGHT (POUNDS) ................ | 4.82E 03 |
| PRESSURE HULL RATING (PSI) ... | 1.00E 04 |
| PRESSURE HULL MATERIAL ....... | STEEL |
| THERMOELECTRIC MATERIAL ...... | PBTE |

FUELING INFORMATION:

| | |
|---|---|
| FUEL TYPE ..................... | SR-90 |
| FUELING DATE ................. | MAR 62 |
| FUELED THERMAL WATTS ......... | 2.11E 02 |
| FUELED CURIES ................ | 3.10E 04 |

ELECTRICAL CHARACTERISTICS: AS OF JAN 71

| | |
|---|---|
| MAXIMUM POWER ................ | 3.90E 00 |
| VOLTAGE AT MAXIMUM POWER ..... | 3.50E 00 |
| CURRENT AT MAXIMUM POWER ..... | 1.11E 00 |



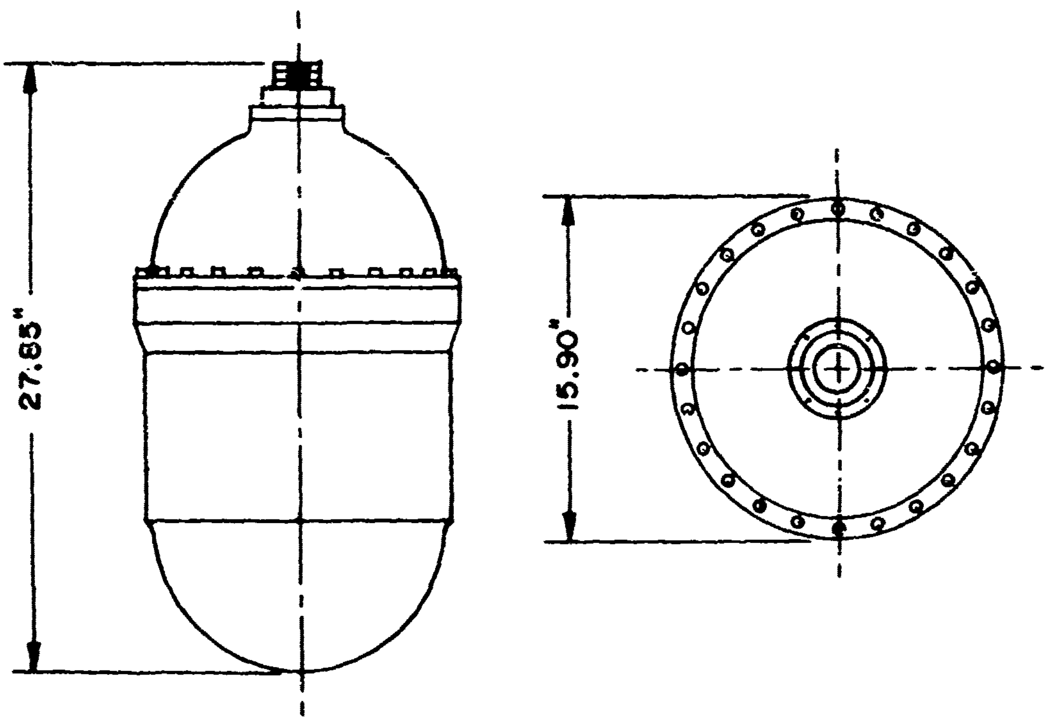

CAUTION

# SNAP-21

APPLICABLE RTG NOS: SP1-SP4, Ø42, Ø43

PHYSICAL CHARACTERISTICS:

| | |
|---|---|
| WEIGHT (POUNDS) ............... | 6.45E Ø |
| PRESSURE HULL RATING (PSI) ... | 1.ØØE Ø |
| PRESSURE HULL MATERIAL ....... | BERYLCI |
| THERMOELECTRIC MATERIAL ...... | PBTE |
| FUEL TYPE .................... | SR-9Ø |



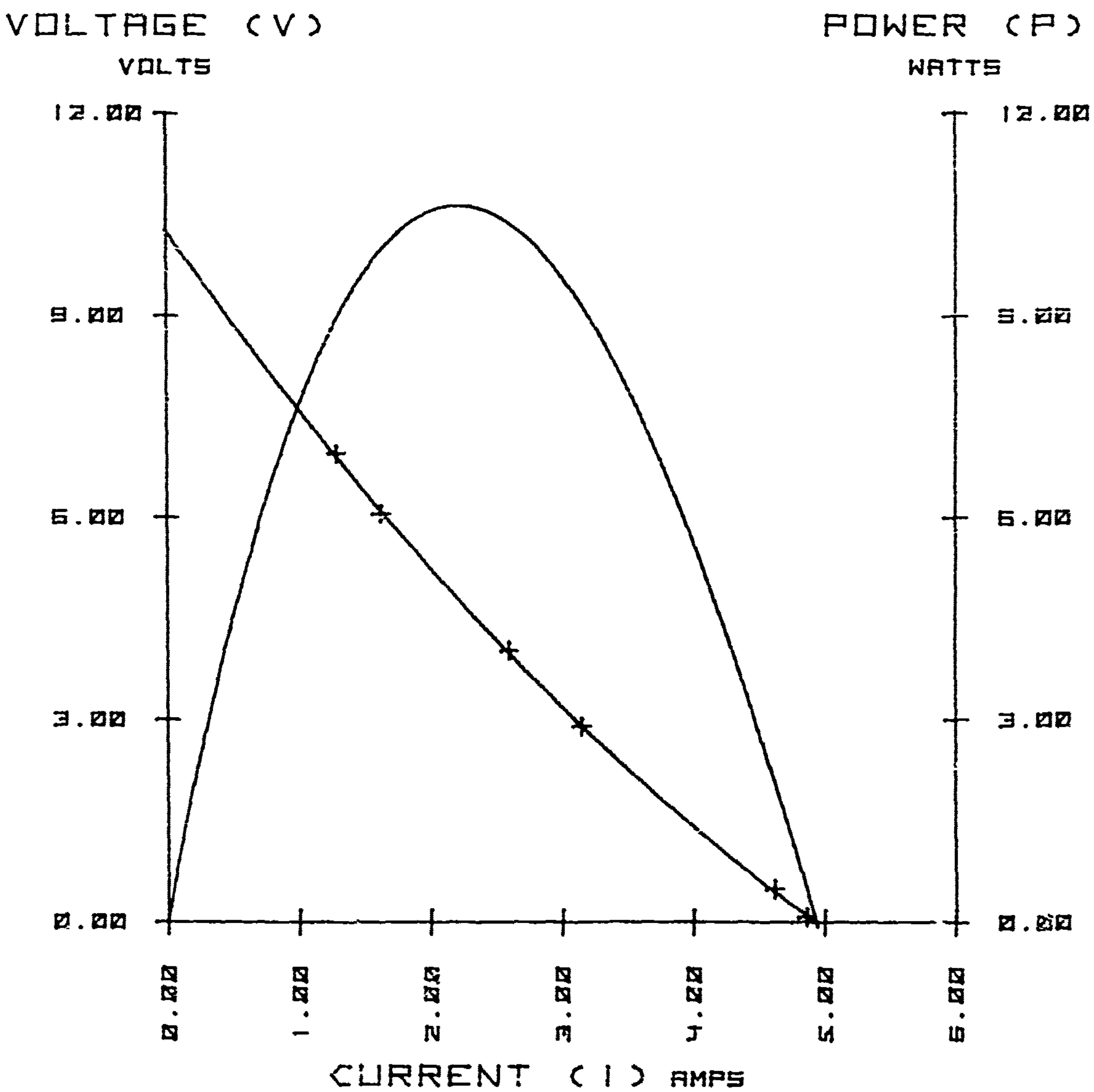
# RTG-043 PERFORMANCE DATA

05 DEC 77
AMBIENT TEMP: 20.5 °C

| | |
|---|---|
| V = A*I*I + B*I + C<br>P = A*I*I*I + B*I*I + C*I | A = 1.43E-01<br>B = -2.78E 00<br>C = 1.03E 01 |

| | |
|---|---|
| MAX POWER................. | 1.06E 01 WATTS |
| VOLTAGE AT MAX POWER.... | 4.78E 00 VOLTS |
| CURRENT AT MAX POWER.... | 2.23E 00 AMPS |
| POWER CONDITIONING...... | NONE |
| THERMAL OUTPUT (WATTS).. | 2.16E 02 |
| FUEL ACTIVITY (CURIES).. | 3.18E 04 |

MAY 71



# SNAP-23A

APPLICABLE RTG NOS: 044

PHYSICAL CHARACTERISTICS:

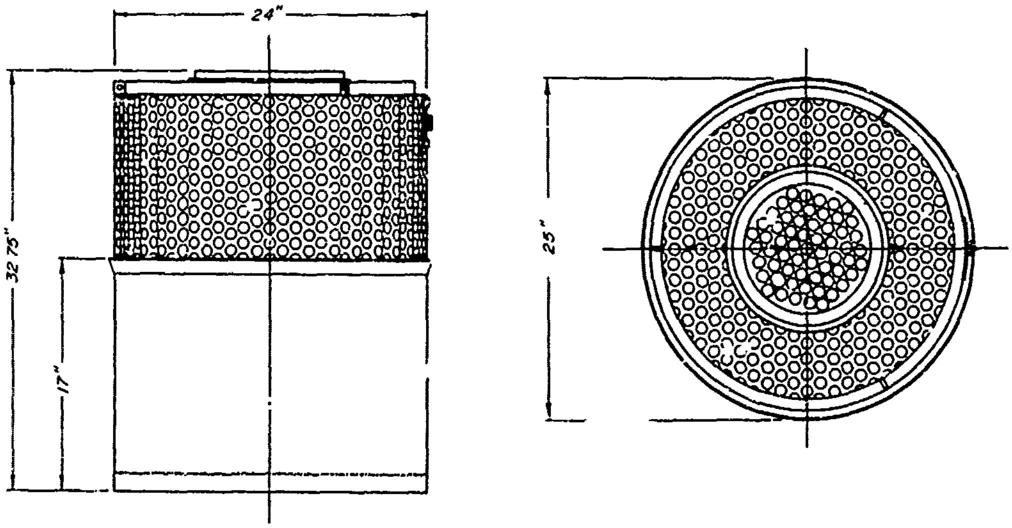
WEIG· :POUNDS) .............. 1.20E 03
PRESS. E HULL RATING (PSI) ... TERRESTRIAL
PRESSURE HULL MATERIAL ....... INCONEL
THERMOELECTRIC MATERIAL ...... PBTE

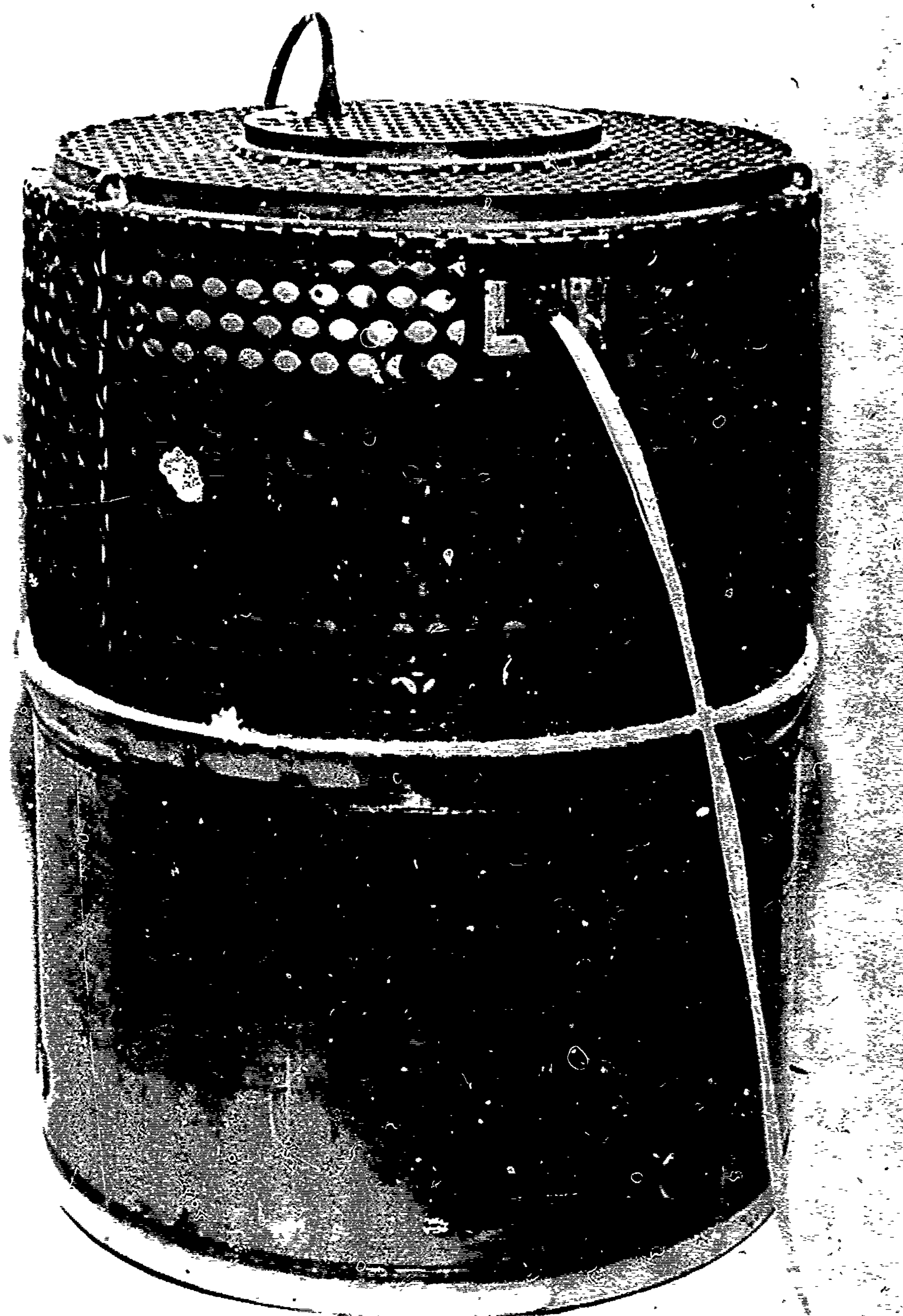
FUELING INFORMATION:

FUEL TYPE .................... SR-90
FUELING DATE ................. NOV 68
FUELED THERMAL WATTS ......... 1.13E 03
FUELED CURIES ................ 1.66E 05

ELECTRICAL CHARACTERISTICS: AS OF JUN 77

MAXIMUM POWER ................ 4.61E 01
VOLTAGE AT MAXIMUM POWER ..... 1.68E 01
CURRENT AT MAXIMUM POWER ..... 2.75E 00



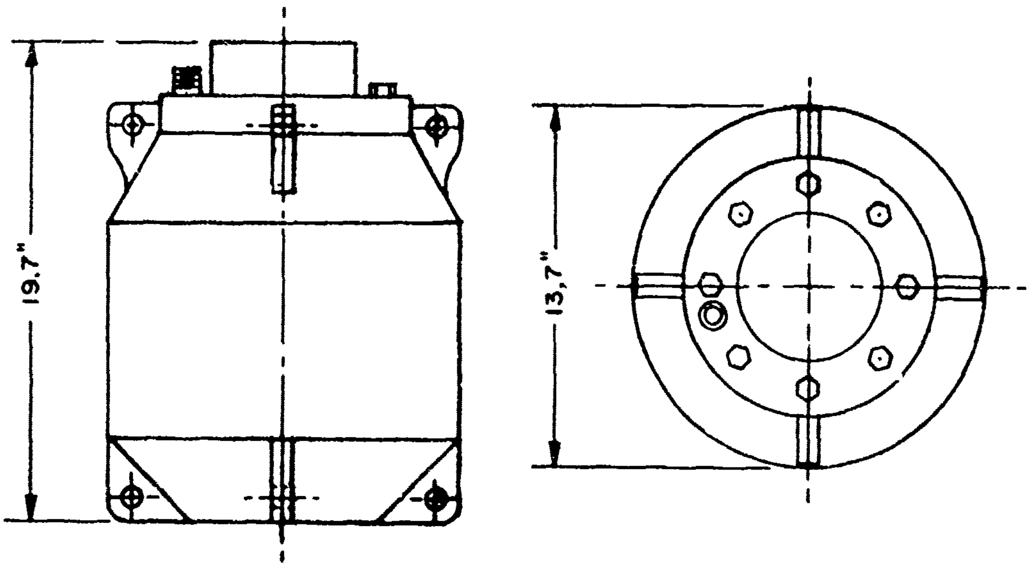


# URIPS-P1

APPLICABLE RTG NOS: 015-018

PHYSICAL CHARACTERISTICS:

| | |
|---|---|
| WEIGHT (POUNDS) .............. | 8.40E 02 |
| PRESSURE HULL RATING (PSI) ... | 1.00E 04 |
| PRESSURE HULL MATERIAL ....... | CU-NI |
| THERMOELECTRIC MATERIAL ...... | BITE |
| FUEL TYPE .................... | SR-90 |



# RTG-017 PERFORMANCE DATA

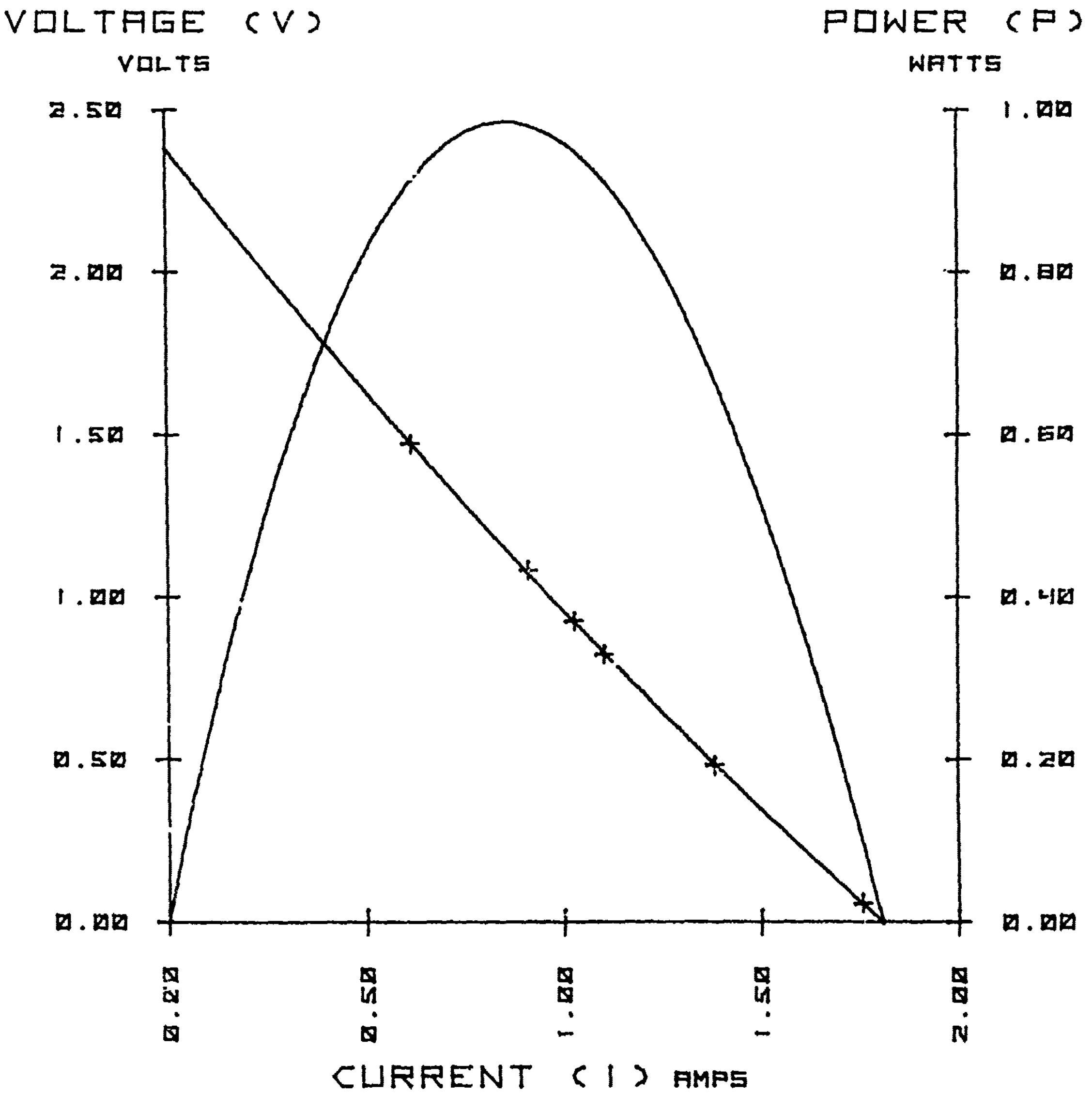
10 JAN 78
AMBIENT TEMP: 19.9 °C

V = A*I*I + B*I + C
P = A*I*I*I + B*I*I + C*I

A = 1.29E-01
B = -1.55E 00
C = 2.38E 00

MAX POWER............... 9.84E-01 WATTS
VOLTAGE AT MAX POWER.... 1.14E 00 VOLTS
CURRENT AT MAX POWER.... 8.61E-01 AMPS
POWER CONDITIONING...... NONE

THERMAL OUTPUT (WATTS).. 5.50E 01
FUEL ACTIVITY (CURIES).. 8.10E 03
JUN 69

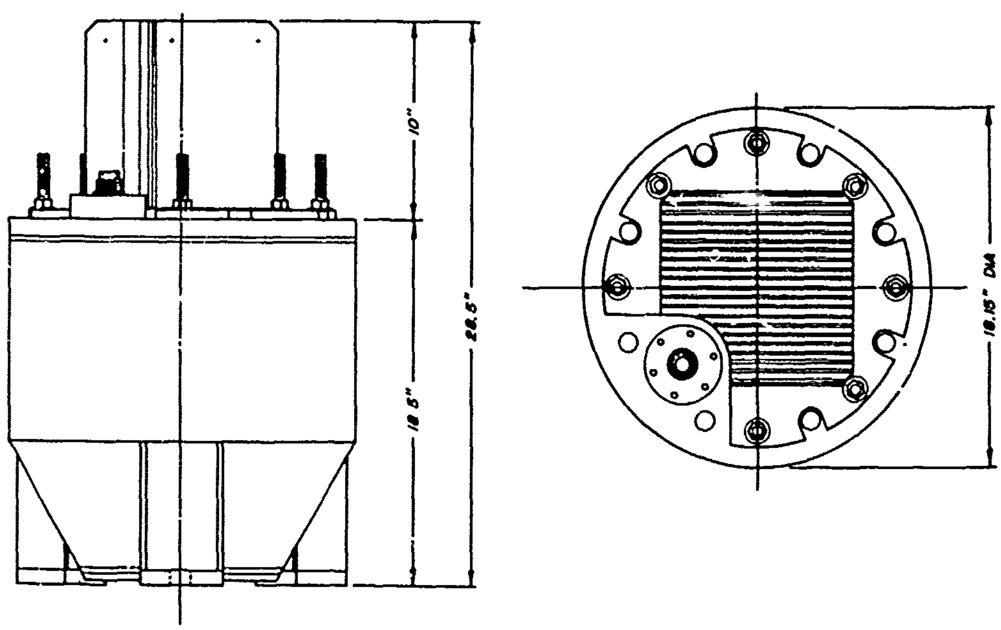


# URIPS-8

APPLICABLE RTG NOS: 025-028

PHYSICAL CHARACTERISTICS:

- WEIGHT (POUNDS) . . . . . . . . . . . . . . 1.76E 03
- PRESSURE HULL RATING (PSI) . . . 5.00E 02
- PRESSURE HULL MATERIAL . . . . . . . . STEEL
- THERMOELECTRIC MATERIAL . . . . . . BITE
- FUEL TYPE . . . . . . . . . . . . . . . . . . . . . . SR-90



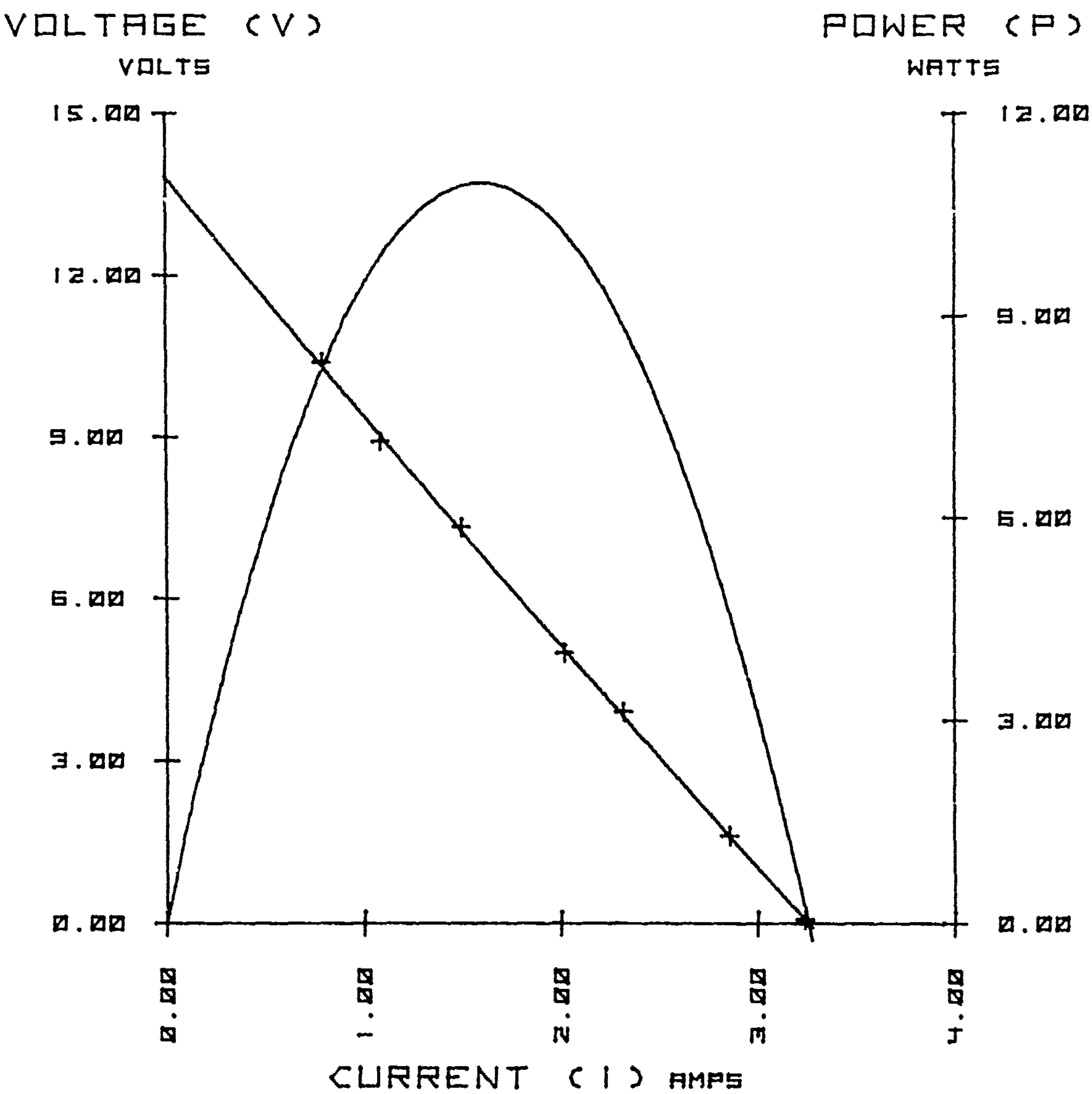
# RTG-025 PERFORMANCE DATA

02 DEC 77
AMBIENT TEMP: 20.5 °C

V = A*I*I + B*I + C
P = A*I*I*I + B*I*I + C*I

A = 7.25E-02
B = -4.47E 00
C = 1.38E 01

| | | |
|---|---|---|
| MAX POWER............... | 1.10E 01 | WATTS |
| VOLTAGE AT MAX POWER.... | 6.82E 00 | VOLTS |
| CURRENT AT MAX POWER.... | 1.61E 00 | AMPS |
| POWER CONDITIONING...... | NONE | |
| THERMAL OUTPUT (WATTS).. | 3.84E 02 | JUN 72 |
| FUEL ACTIVITY (CURIES).. | 5.65E 04 | JUN 72 |



# CHAPTER FIVE

## RADIOISOTOPE THERMOELECTRIC GENERATORS AVAILABLE FOR LOAN

**5.1 INTRODUCTION.** The Navy has in its inventory a number of RTGs that can be provided on a loan basis to federal agencies for worthwhile projects. Electrical characteristics of the currently available generators are listed below. Should none of these RTGs suit your project requirements, other solutions are possible. Series-parallel combinations of various generators, use of power conditioning equipment, and/or procurement of different models provide a wide range of voltage and power. For additional information or technical assistance in determining suitability to your special application, contact the Naval Nuclear Power Unit, Port Hueneme, CA. Telephone (805) 982-5323 or AUTOVON 360-5323.

### 5.2 RTGs AVAILABLE FOR LOAN.

| Power (watts) | Voltage (volts) | Model | RTG No. |
|---|---|---|---|
| 0.31 | 1.22 | IMPS | MRTG 1 |
| 0.53 | 6.51 | Half-Watt | GP0003 |
| 0.41 | 5.73 | Half-Watt | GP0004 |
| 0.51 | 6.42 | Half-Watt | TP0005 |
| 0.42 | 7.04 | Half-Watt | NP0007 |
| 0.41 | 8.15 | Half-Watt | NP0008 |
| 0.98 | 1.14 | URIPS-P1 | 017 |
| 1.27 | 24.7 | Millibatt-1000 | 033 |
| 1.27 | 24.7 | Millibatt-1000 | 034 |
| 1.27 | 24.7 | Millibatt-1000 | 035 |
| 1.27 | 24.7 | Millibatt-1000 | 036 |
| 1.27 | 24.7 | Millibatt-1000 | 039 |
| 1.27 | 24.7 | Millibatt-1000 | 040 |
| 9.82 | 4.51 | SNAP-21 | SP4 |
| 24.5 | 2.53 | Sentinel-25C1 | 006 |
| 25.1 | 2.72 | Sentinel-25C3 | 014 |
| 26.5 | 2.69 | Sentinel-25E | 013 |
| 26.7 | 2.68 | Sentinel-25E | 011 |
| 27.1 | 2.63 | Sentinel-25E | 012 |
| 35.4 | 3.10 | Sentinel-25F | 020 |
| 37.8 | 3.51 | Sentinel-25E | 032 |
| 39.5 | 3.58 | Sentinel-25E | 031 |

# CHAPTER SIX

# OBTAINING A RADIOISOTOPE THERMOELECTRIC GENERATOR

**6.1 PROCEDURE.** Requests for RTGs should be forwarded to the Officer in Charge (Code 70) Naval Nuclear Power Unit, Port Hueneme, CA 93043. The request should include information describing the system to be powered by the RTG(s), its power and voltage requirements, the length of the mission, the location of the mission, the ambient pressure and temperature, and any weight or size limitations which may exist.

## 6.2 SERVICES PROVIDED BY THE NAVAL NUCLEAR POWER UNIT (NAVNUPWRU)

### 6.2.1 NAVY CUSTOMERS.

**6.2.1.1 Procurement.** NAVNUPWRU will provide RTGs from the Navy's existing inventory or assist the User in writing specifications for new RTG(s) and contract for procurement with funds provided by the User.

**6.2.1.2 Shipping.** NAVNUPWRU will coordinate and schedule all RTG shipments.

**6.2.1.3 Training.** NAVNUPWRU will provide radiological safety training for personnel who will use and be responsible for the RTG(s).

**6.2.1.4 RTG Operation and Safety Plan Preparation.** NAVNUPWRU will assist the User in preparing this plan.

**6.2.1.5 Radiological Safety Support.** NAVNUPWRU will provide all, or part of the support required to assure radiological safety during the implant mission, depending upon the capabilities of the User.

### 6.2.2 OTHER FEDERAL GOVERNMENT CUSTOMERS.

**6.2.2.1 Procurement.** NAVNUPWRU will loan RTGs to other federal agencies so long as the loan does not interfere with Navy requirements and the proper Nuclear Regulatory Commission License has been obtained. If satisfactory RTGs do not exist in the Navy's inventory, NAVNUPWRU will provide basic procurement guidance to the agency desiring RTGs.

**6.2.2.2 Shipping.** NAVNUPWRU will assist users in coordinating and scheduling RTG shipments.

**6.2.2.3 Training.** NAVNUPWRU will provide radiological safety training to user personnel on a cost reimbursable basis.

**6.2.2.4 NRC Licence Application.** NAVNUPWRU will provide basic instructions on the preparation of the NRC license application.

**6.2.2.5 Radiological Safety Support.** NAVNUPWRU will provide the support required to assure radiological safety during the implant mission on a cost reimbursable basis.

## 6.3 COST.

**6.3.1 NAVY CUSTOMERS.** Users must pay for hardware required to mate the RTG(s) to the system it will power and transportation charges for shipments outside the limits of the Continental United States.

**6.3.2 OTHER FEDERAL GOVERNMENT CUSTOMERS.** Users must pay for hardware required to mate the RTG(s) to the system it will power and all shipping charges.

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